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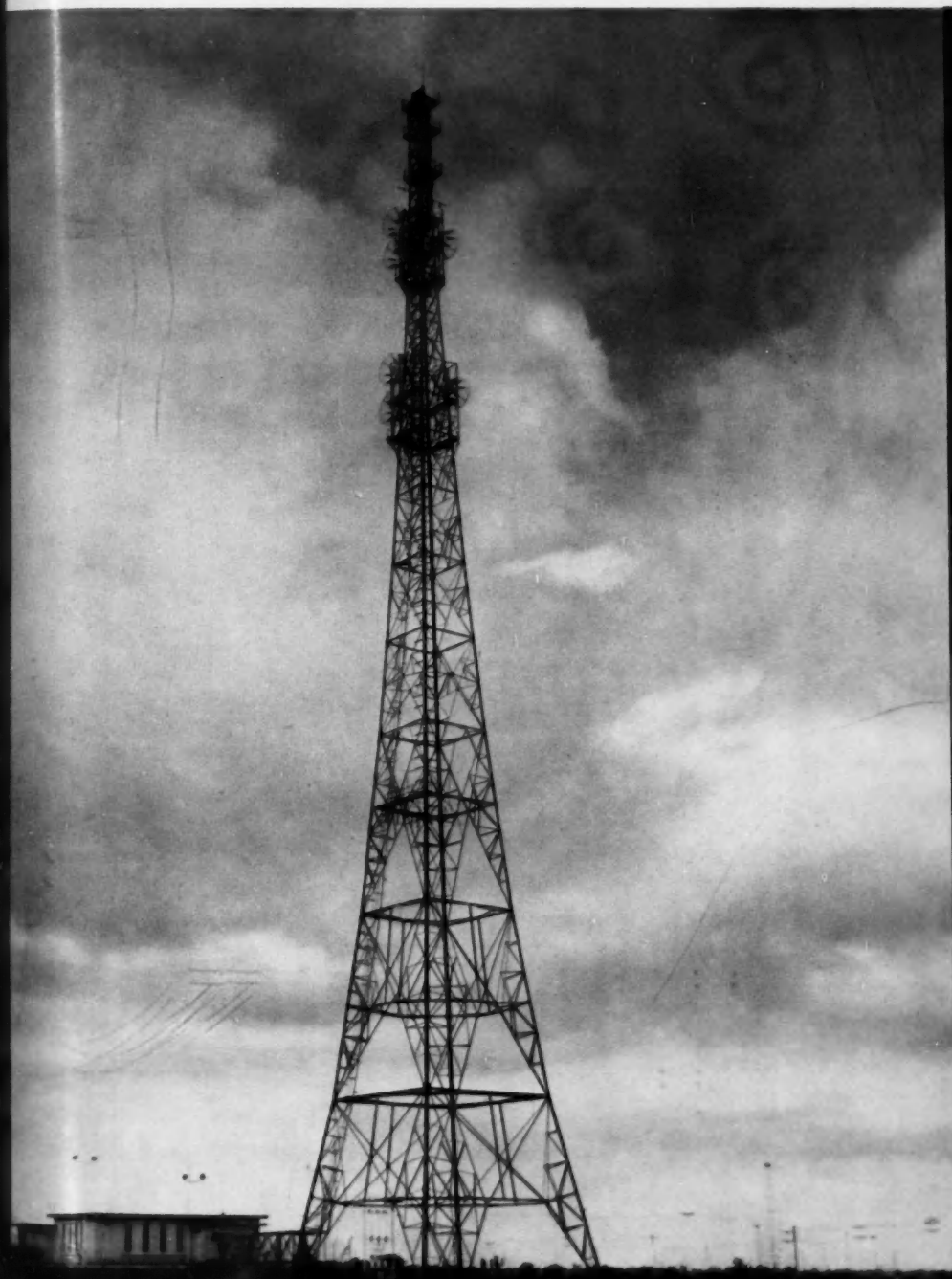

THE GENERAL
ELECTRIC CO. LTD.
OF ENGLAND

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G.E.C. JOURNAL

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COVER PICTURE

A 350 ft. radio tower designed and supplied by Pirelli-General for the Compania Shell de Venezuela. This tower forms a focal point of the V.H.F. radio system linking drilling sites in one of C.S.V.'s fields.

The Lillehei bubble oxygenator at Guy's Hospital, London, which takes over the functions of the heart and lung during cardiac operations. It incorporates heating apparatus, developed by the G.E.C., to keep the blood at constant body temperature.

Automatic Skip Winder at Cwm Colliery

By W. R. COX, B.E. (Elect.) N.Z., A.M.I.E.E.,
Witton Engineering Works.

In the foreword of a booklet "British Coal, the Rebirth of an Industry", recently published by the National Coal Board to mark the first ten years of public ownership, Mr. James Bowman, Chairman of the Board, says, "As the great construction schemes come to completion Britain will have . . . one of the most progressive coal mining industries in the world." The installation described in the following article is an excellent example of what is being done in this direction.

THE project for modernising Cwm Colliery in the Rhondda area of South Wales is of the greatest importance to the mining communities over a wide area of Glamorganshire. When reconstruction is completed, which is expected in four to five years' time, Cwm Colliery will be the biggest of the South Wales pits, and will open up the huge reserves of top grade coking coal which lie beneath 10 square miles of the Glamorgan countryside.

Cwm is already linked underground with the Maritime colliery and will shortly be connected with the workings at Coedely. Miners at both these pits will continue to go underground by their local shafts, but all the coal will be raised at Cwm, where the centralised coal washery and coke oven plant are situated.

In connection with this important project, contracts were placed with The General Electric Co. Ltd. covering an a.c. fully automatic 3,000 h.p. skip winder, a double-drum service winder, coal preparation plant and two 8,000 kW turbo-alternators ; and with Qualter Hall & Co. Ltd. for the skip plant and spiral chutes. This article is concerned with the

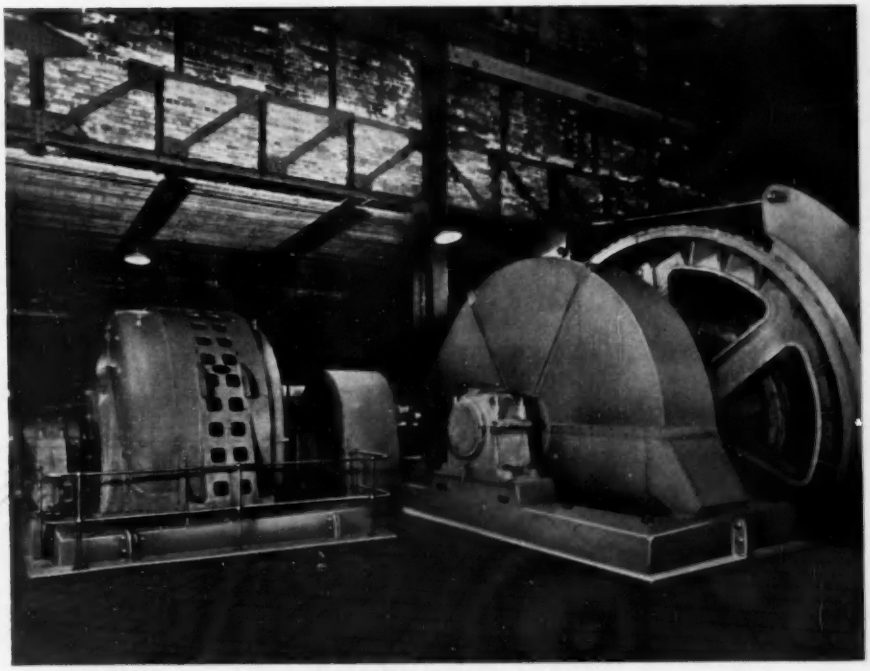


Fig. 1.—The 3,000 h.p. automatic skip winder.

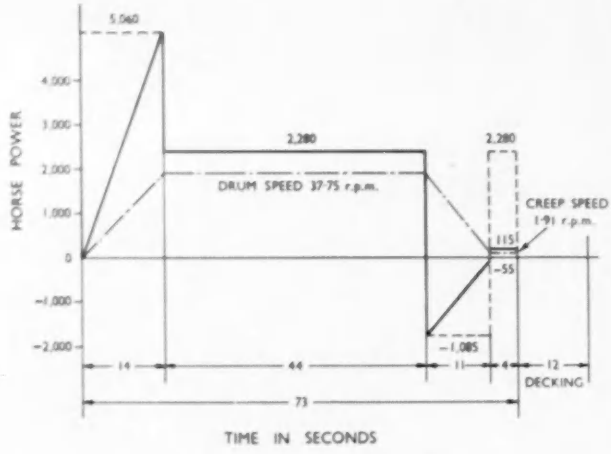


Fig. 2.—Horsepower/time diagram.

a.c. winding plant, which is of particular interest in that it is the first fully automatic winder to be commissioned using the G.E.C. patented system of speed control,* and is also the first to operate at 11,000 volts.

MECHANICAL FEATURES.

The winding engine (fig. 1), which has a single parallel drum, 20 ft. diameter by 13 ft. wide, is driven through a double helical single-reduction gear by a 3,000 h.p., 11,000 volt slipring motor and is designed to raise 510 tons of coal per hour from a depth of 2,268 ft. Two skips, each of 12 tons capacity, with guillotine discharge doors, are used in balance.

From the horsepower/time diagram (fig. 2) it will be seen that the time of a complete winding cycle is 85 seconds, giving 42 winds per hour.

In addition to the usual methods of brake control by hand and by the emergency brake solenoid, an electropneumatic device serves to apply the brakes when the winder is on automatic or pushbutton operation.

As shown in the diagrammatic layout of the plant (fig. 4), coal from workings at two levels is fed by mine car tipplers via an apron plate feeder on to a conveyor belt, the coal from the upper level descending through spiral chutes.

The conveyor transports the coal to the bottom of the shaft where it is fed through a bifurcated chute into two weighing pockets, one for each skip. Loading of the empty skips from the weighing pockets is automatic and is initiated by pneumatic valves which are operated by skates on the skips, so that for running the plant below ground men are only called upon to work the tipplers.

On reaching the pit head, the guillotine discharge door of the skip is opened by an electric magnet which is raised pneumatically so that the coal is released into receiving hoppers which feed the conveyor belt leading to the washery. After a predetermined time delay, the skip door is automatically closed and the magnet released. Pneumatically-operated doors in each hopper are interlocked so that only one can be opened at a time, thus forming an air-lock.

The handling plant referred to above was designed and supplied by Qualter Hall & Co. Ltd., and is fully interlocked. Should both weighing pockets at the pit bottom be full, the conveyor is stopped but automatically restarts as soon as one of the pockets has been emptied. Similarly, if a full skip arrives at bank before the appropriate hopper has been cleared of coal, the discharge sequence is automatically delayed by pneumatic and mechanical interlocks until that hopper has been cleared.

STATOR REVERSER.

Before describing the system of automatic control, and the special apparatus associated with its performance, the stator reverser (fig. 3) is deserving of mention as it is the first of its type to be built for 11,000 volt service.

The contactors are rated at 300 A and the equipment fully satisfied the most stringent tests at the Works, where it operated successfully when breaking 900 A. The equipment also satisfactorily withstood the normal flash test at 28·5 kV and an impulse test of 70 kV.

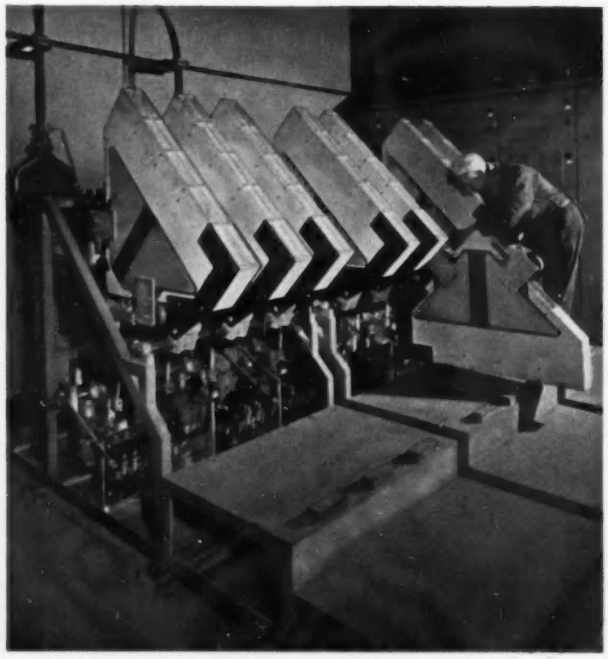


Fig. 3.—11,000 volt stator reverser, with one arc chute lowered for inspection of contacts.

* *G.E.C. Journal*, Vol. 20, pp. 161-167, July, 1953.

The reverser is air-operated through electro-pneumatic valves and is smooth and positive both on opening and closing. Normally the mine air supply is used but a standby compressor starts automatically in the event of failure of the normal air supply. This compressor is also used during periods when the main colliery air compressors are not working. Should the air pressure fall below the value necessary to ensure reliable operation of the contactors, a pressure switch in the winder safety circuit trips the main circuit breaker and locks out the winder.

THE CONTROL SCHEME.

The method of control is a patented closed loop system, which ensures a close relationship between the steady rope speed and the position of the driver's lever, and includes an overriding torque limitation feature. The speed of the winder is determined by comparing, in the control circuit, the performance of the plant with that called for by a pattern potentiometer. Any out-of-balance in the control circuit automatically results in an increase in the driving torque or the application of dynamic braking as may be required to increase or decrease the winder speed until the chosen speed is reached and the state of balance is restored.

This system of control was first used for the 1,100 h.p. a.c. winder at the Avon Colliery, commissioned nearly three years ago, and has since been installed at a number of pits in the country. The 3,000 h.p. plant

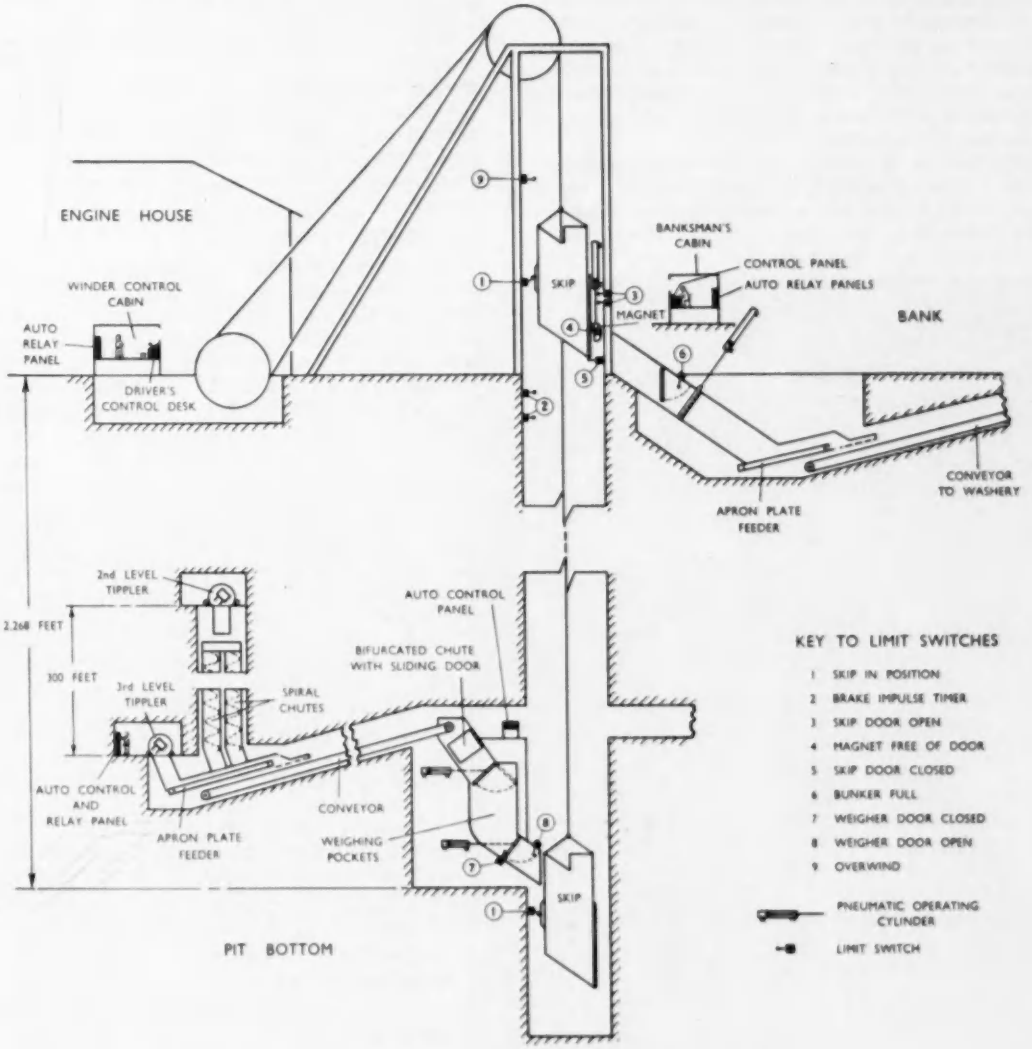


Fig. 4.—Layout of the winding plant.

at Cwm is the first to be arranged for fully automatic working using this system of speed control.

Three methods of control are available, namely :

(1) Cyclic automatic winding, in which the complete installation operates without human aid and winding continues automatically so long as coal is available at the bottom of the shaft and is cleared at bank.

(2) Pushbutton control, in which winding is under the control of the banksman and onsetter.

(3) Manual control by the winding engineman. This is always used for shaft and rope inspection and on the rare occasions when winding men.

A control and indicating panel is situated below ground near the mine car tippler, above ground at bank and in the driver's cabin. Each panel is equipped with a four-way switch with " off ", " automatic ", " pushbutton " and " manual " positions. Also mounted on the panel are the " start " pushbutton, " emergency stop " pushbutton, control circuit isolator and indicating lamps which convey to the operator the sequence of operations of the plant and provide visual indication of the occurrence of a fault.

A further panel, located near the loading equipment at the bottom of the shaft, is provided with an " emergency stop " button and indicating lamps to show the type of control in use and the occurrence of a lockout. Normally no one is stationed at this point and the panel is used mainly during maintenance work.

AUTOMATIC CYCLIC WINDING.

The automatic sequence is brought into operation by the onsetter, banksman and driver setting their selector switches to " automatic ".

The driver's lever is declutched and the mechanical brake lever moved to its " off " position. It should be noted that the mechanical brake lever is effective at all times and can be used in an emergency when operating on automatic control. On completion of the " start " circuit, the pattern potentiometer is electrically driven to its maximum speed position, thereby applying a starting torque to the winder motor, the direction of drive being determined by the " skip in position " switches. As soon as the torque reaches a predetermined value, a current relay releases the electrically-operated brakes and the winder accelerates to its maximum speed. Thereafter deceleration and decking follow automatically and the winder continues to raise coal without further human intervention. It is usual for the winding engineman to remain in the winder house and an alarm bell is provided to warn him of a lockout. He is also able to change the plant over to manual control in an emergency without any action being taken by the onsetter or banksman.

During automatic winding, the sequence of events is governed by a system of relays which are arranged to fail to safety so that the occurrence of any fault would stop the plant.

When on fully automatic control, retardation of the winder is governed by long-range precision cams which return the pattern speed potentiometer from its full speed position to the creep speed setting. The cam mechanism is designed in such a way that the full cam profile, representing 300°, is effective during the deceleration period and hence a high degree of precision is attained. It should be noted that accelerating cams are not necessary as acceleration of the winder is under the control of the maximum torque limit imposed by the speed control system.

In connection with the automatic control scheme, the creep speed regulator and the brake impulse timer are of special interest. The former ensures that the creep speed is substantially constant for varying loads, while the latter determines the instant of application of the brakes. The decking accuracy with normal variation of load is within $\pm$ 2 in.

CREEP SPEED REGULATOR.

While the winder is running at full speed, its load current is used to adjust the creep speed regulator automatically by an amount dependent upon the load. On entering the retardation zone, this correction is applied to the closed loop signal circuit through the pattern potentiometer, thereby ensuring that the chosen creep speed is uninfluenced by changes in load.

BRAKE IMPULSE TIMER.

This apparatus determines the instant at which the brakes are applied and takes into consideration any variations that may occur in the creep speed so that final stopping takes place at the same point. The creep speed of the winder is measured by timing the passage of the skip between two limit switches mounted near to the top of the shaft, and the instant of initiating brake application is adjusted accordingly.

PUSHBUTTON CONTROL.

For pushbutton control, the selector switches at the three control points, to which reference has already been made, must all be set correctly. The driver's lever is disengaged and the mechanical brake lever moved to the " off " position.

The operation of the winder is similar to that already described for automatic winding, but in this instance starting is instigated by the onsetter and banksman. After ascertaining from the various indicating lamps that everything is ready below ground for the start of a wind, the onsetter, who is stationed alongside the tippler, presses his "start" pushbutton. In like manner the banksman checks that all is ready at the pit head and presses his " start " pushbutton. When both have taken this action the winder starts, accelerates and banks automatically without the intervention of the winding engineman. With this form of control, loading and discharging of the skips is fully automatic.

MANUAL OPERATION.

When on manual control the winder is controlled in the orthodox manner by the driver following the usual bell signals from the onsetter and the banksman.

The patented system of speed control ensures that the speed of the winder follows the position of the driver's lever, driving or dynamic braking being applied automatically to the motor as may be required to preserve the chosen speed. Provision is made in the usual way whereby the driver may override the precision cams during the deceleration period.

Loading of the skips at the bottom of the shafts is automatic and lamp signals inform the onsetter when a skip is full. Discharging of the skips at the pit head is under the control of the banksman, who is advised by lamp signals when a skip is in position. As he cannot see the discharge gate of the skip, further lamps indicate whether this gate is open or closed.

PROTECTION.

The protection of the winder follows standard practice but includes certain additional features which are desirable for automatic control. As already mentioned, a relay failure or circuit fault when on automatic or pushbutton winding shuts down the plant. Every precaution is taken to eliminate the likelihood of faulty operation by duplicating essential relays and pilot control wiring, which is split between two multicore cables, one on each side of the shaft.

Should an emergency trip stop the winder in midshaft the controls must be set to " manual " and the driver must use his power and brake levers in the orthodox manner to bring the winder to bank.

ACKNOWLEDGMENT.

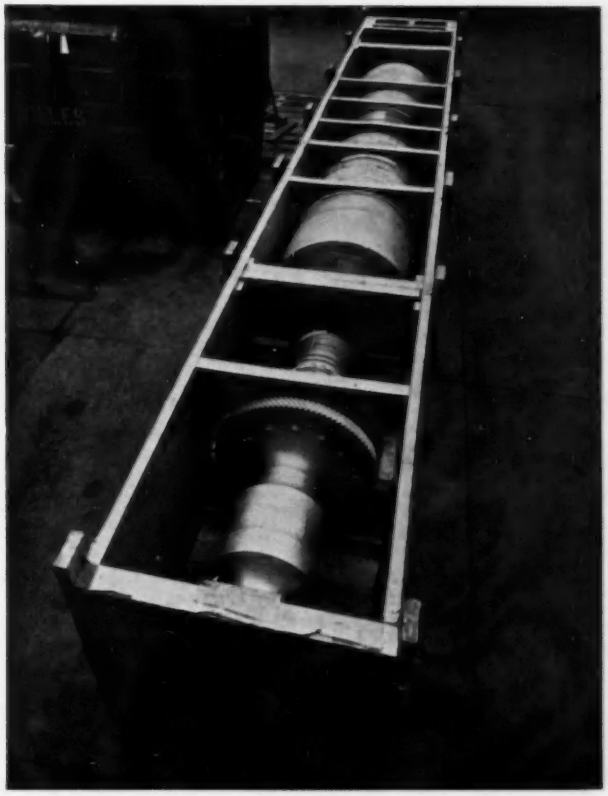
Acknowledgment is made to the National Coal Board for the facilities given to photograph this installation and permission to publish this description.

Protective Packing of Rotors

Where conditions of transport and storage overseas may result in prolonged exposure to moisture, the G.E.C. has adopted the practice of sealing heavy electrical equipment hermetically in a plastics " cocoon ". The accompanying illustration shows a 30 MW turbo-alternator rotor for the Orlando power station, Johannesburg, prepared by this process for shipment. The main body is protected by a covering of calendered material, on to which the plastics material is sprayed in solution but elsewhere the plastics envelope is built up by spraying direct on to the parts to be protected. Finally, bags of desiccant are introduced to take up residual moisture and a silica-gel indicator is inserted behind a " Perspex " window to give visual indication if moisture penetrates as a result of damage to the protective covering.

A rotor protected in this way was found when removed from its crate to have been standing in a foot of water, severe rain having been experienced while it was stored outside the power station. Normally a long dry-out period would have been necessary, but on this occasion the silica-gel indicators showed that the rotor itself had kept perfectly dry.

The protective process is carried out by R. A. Brand & Co. Ltd.



An Automatic Telephone Exchange in Sarawak

By B. DRAPER, A.M.I.E.E.,
Telephone Works, Coventry.

This article describes briefly the modern automatic telephone exchange at Kuching in Sarawak, and includes an outline of the operation of the Strowger system of telephony used in the large majority of the world's automatic telephone exchanges. The exchange equipment was manufactured and installed by the Telephone Works of the G.E.C. Kuching is situated well within the tropics, hence all the equipment is treated to withstand extreme climatic conditions.

THE Kuching exchange, Sarawak (fig. 1), has an initial capacity for 2,000 lines. In addition to selecting the required line, and establishing a through connection for speech from one subscriber to another, the automatic equipment must perform all the other subsidiary duties that are carried by an operator in a manual exchange; for example, connect ringing tone and current, busy tone, and number-unobtainable tone, at the appropriate times. The equipment also gives subscribers access to a manual board for trunk calls and to the engineers for maintenance services.

Fig. 1.—The exchange building at Kuching.

METHOD OF OPERATION.

The motion of the electro-magnetically operated selectors, which are used to select a line, is controlled by signals generated by the subscriber's dial during dialling. These signals consist of trains of pulses, the number of pulses in each signal being equal to the digit dialled.

A selector consists of a shaft which can be stepped in both a vertical and a rotary direction by a vertical and a rotary electro-magnet respectively. Two or more wipers are mounted on the shaft, and the selector is mounted in front of a bank of a hundred contacts arranged in ten arcs, each of ten contacts (fig. 2). This arrangement of contacts on a simple ten by ten decimal basis makes the Strowger system of working particularly simple to understand.

When the selector is at rest the wipers lie below the first arc or level. The vertical motion lifts the wipers until they are in line with a particular level, and the rotary motion steps the wipers to a particular contact in that level. The selectors, known as two-

motion selectors to distinguish them from uniselectors, which only have rotary motion, are common to many subscribers, and sufficient are provided to carry the traffic at the peak period. This is possible because only a proportion of the subscribers on the exchange is likely to originate a call at any one time.

Since the two-motion selectors are common equipment, some other equipment must be provided, which is peculiar to a particular subscriber, to give access to the common equipment. At Kuching this is done by means of uniselectors, of which there is one (fig. 3) for each subscriber's line. A wiper assembly is driven by electro-magnetic action, contact by contact, over a semi-circular bank of twenty-five contacts. The subscriber's line is connected to the wipers, and the bank contacts are wired to two-motion selectors. The first outlets from a number of uniselectors are multipled together and connected to a two-motion selector. This is repeated for later outlets from the uniselector. In this way the number of first selectors required is less than the number of subscribers. The actual number of selectors fitted varies from one exchange to another ; in Kuching allowance has been made for 200 such selectors, i.e. one for every ten subscribers. This is because it has been estimated that in the busiest periods not more than one subscriber in every ten will want to make a call at any one time.

Setting up a Call.

When a subscriber lifts his handset to make a call, his uniselector hunts round its bank until it finds a free outlet to a selector. The uniselector stops on this outlet, and dial tone is returned from the selector to tell the caller that the circuit is ready for him to dial. Suppose the caller requires the number 2345. On hearing dial tone he dials the first digit " 2 ". This causes two pulses to be transmitted to the exchange to actuate the vertical stepping magnet in the selector. The selector takes two steps vertically. The wipers then hunt automatically round the second level to find a free outlet to another selector, similar to the hunting of the uniselectors. This operation establishes that the number required is in the group 2000-2999 since only this group is accessible from level 2 of the selector ; for this reason these selectors are known as group selectors, and because this is the first stage in a series of selection stages, the selectors here are known as first group selectors. The selectors wired to the banks of the first group selectors are second group selectors.

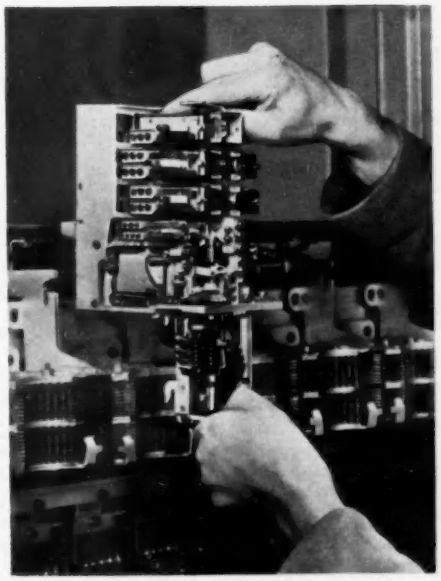


Fig. 2.—Fitting a selector into a bank.

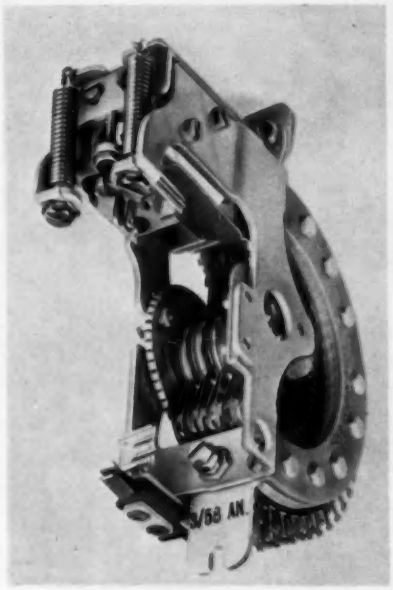
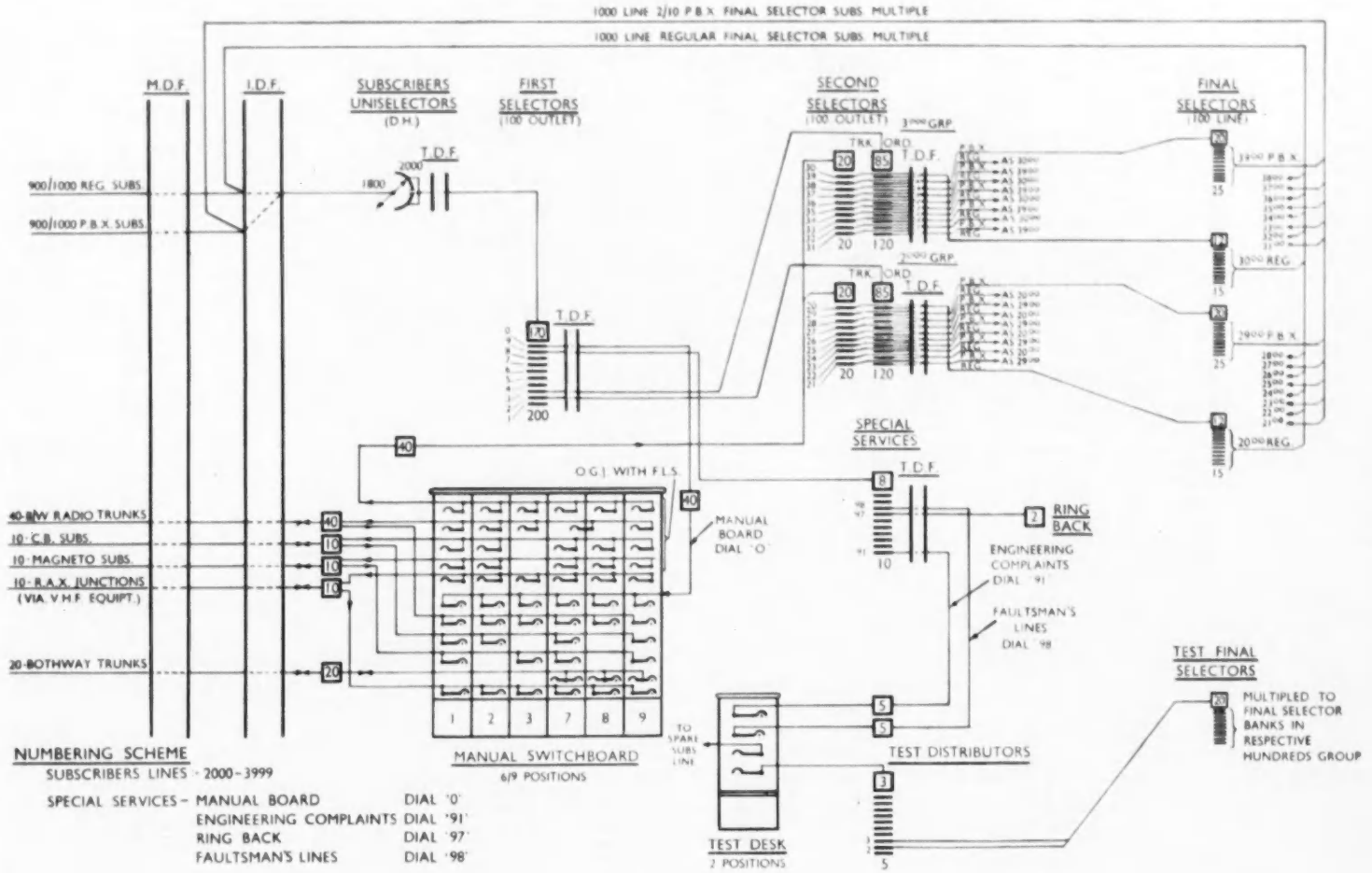


Fig. 3.—Subscriber's uniselector.

The speed of operation of the equipment is such that no matter how fast the caller dials, the second selector is ready to receive the train of pulses corresponding to the second digit dialled ; therefore it is not necessary to connect dial tone from any stage after the first group selector. The second train of pulses steps the second selector to level " 3 " and the wipers hunt round the bank to find a free outlet to a final selector in the 2300 group. As the bank of a two-motion selector has a hundred outlets, a subscriber's line in the group 2300-2399 can be connected to each of the outlets in this group of final selectors.

On receipt of the third digit " 4 " the final selector steps to level " 4 ", but does not hunt round the bank. The five pulses corresponding to the fourth digit actuate the rotary magnet to step the final selector



KEY

R.A.X.—Rural automatic exchange.
M.D.F.—Main distribution frame.
I.D.F.—Intermediate distribution frame.
O.G.J.—Outgoing junction.
T.D.F.—Trunk distribution frame.
ORD—Selectors with access from subscribers.
REG—Final selectors serving single-line subscribers.
F.L.S.—Free-line singnalling.

Fig. 4.—Trunking diagram—Kuching exchange.

wipers to the fifth contact, to which is connected subscriber number 2345. Thus, from the 2,000 lines connected to the exchange, any calling subscriber can be connected automatically to the subscriber he requires.

Called Subscriber Free.

When the wipers come to rest on the wanted subscriber's line, the final selector tests the line for free or busy conditions. If the line is free, the final selector connects ringing current to the called subscriber's line to ring the bell, and ringing tone to the caller to indicate that the wanted party is being called. When the call is answered, the final selector disconnects the ringing current and tone, and connects the two lines for speech. A pulse is also fed to the calling subscriber's meter to register the completed call so that it can be charged for at a later date.

Called Subscriber Busy.

When the final selector finds that the wanted line is already in use, busy tone is connected to the caller. No pulse is fed to the subscriber's meter.

TRUNKING DIAGRAM.

The trunking diagram for Kuching Exchange in fig. 4 shows how all calls are routed through the exchange. Each subscriber's telephone is connected to the exchange by a pair of wires which are terminated on the line side of the main distribution frame (M.D.F.). The line is extended via the M.D.F. and the intermediate distribution frame (I.D.F.) to the subscriber's line circuit. This comprises the uniselector already mentioned, and two line relays ; each subscriber's line has its own individual line circuit. The use of the two distribution frames gives a highly flexible means of connecting each of the incoming lines to any line circuit so that the traffic density can be spread evenly throughout the exchange. The M.D.F. also houses protection equipment to protect the exchange apparatus against any high voltages or heavy currents that may be introduced into the telephone lines due to lightning or by contact with high-voltage lines.

When a subscriber lifts his handset to originate a call, a switch inside the instrument closes to connect a loop across the two lines ; this causes the uniselector to hunt for a free first selector. When the caller dials a number, the dial breaks the loop a number of times equal to the digit dialled, and these pulses control the routing of the call through the exchange as already explained.

On the completion of the conversation, both parties replace their handsets, the selectors in the exchange restore to their normal positions, and the two-motion selectors become available for use by other subscribers. If either subscriber does not replace his handset, after a short interval of time an alarm will sound in the exchange. This attracts the maintenance engineer, who can speak on the line to request the subscriber to replace the handset. Such an alarm system is necessary because if several subscribers hold common equipment longer than necessary, there is a chance that traffic through the exchange would be dislocated.

If, when a subscriber dials a number, say 2345, all the second selectors wired to level " 2 " of the first selector are in use, the first selector will step over all ten contacts, and come to rest on an eleventh contact. Busy tone is returned to the caller to indicate that all the switches at this stage are in use ; at the same time a level overflow meter operates. This tells the maintenance staff that a caller has been

Fig. 5.—Manual board.

unsuccessful in completing a call due to congestion at this stage, and if many calls fail in this way steps are taken to increase the number of switches available.

The number and duration of calls originated by the subscribers are estimated by local traffic observations. Tables based on a formula of mathematical probability have been compiled to convert these estimated traffic figures into switch quantities required at each stage in the exchange. At Kuching provision has been made for 200 first-group selectors, 240 ordinary second-group selectors, and 15 ordinary final selectors per hundred lines, or 25 private branch exchange (P.B.X.) final selectors per hundred lines. Groups of a hundred lines through the exchange numbering scheme are allocated alternately to ordinary subscribers and private branch exchanges. A P.B.X. is where a subscriber has more than one line to the telephone exchange, numbered

consecutively. The P.B.X. final selectors are specially arranged so that when a caller dials the first line in a subscriber's number, if that line is engaged, the selector steps automatically to the second line, and so on until a free line is found, when the selector connects ringing current and tone as an ordinary final selector. Only if all lines to the wanted subscriber are engaged is busy tone returned to the caller.

SPECIAL SERVICES.

At Kuching, since only two levels are used on the first selectors for the initial capacity of 2,000 subscribers' lines, there are levels free for special services and for future extensions to the system. For example, level " 0 " is wired direct to the manual board (fig. 5). Any subscriber connected to the automatic exchange who desires to call a subscriber on a neighbouring exchange, or who wants to make a trunk call, dials the single digit " 0 " and is connected to a free line to the manual board. A lamp lights on the switchboard to indicate to the operator that a call is waiting. The operator answers the call and completes the required connection.

Similarly, all incoming calls from other exchanges are routed via the switchboard. To save time in setting up a call, the local lines from the operators' positions are connected direct to the second selectors, one set to the 2000 group and another set to the 3000 group. Thus the operator only dials the last three digits of the wanted number. If the wanted party is engaged the operator has a trunk-offering facility that enables her to break in on a call to offer the long-distance connection.

Fig. 7.—Racks of automatic equipment.

Special-service lines are routed via level " 9 " of the first selectors and a special second-group selector.

Fig. 6.—Test desk and main distribution frame.

By dialling " 91 " a subscriber is connected to the complaints position on the test desk (fig. 6). " 98 " is also wired to the test desk, but these lines are reserved for the use of line and subscribers' maintenance engineers. Two ring-back circuits are wired to level "97" for the use of maintenance engineers. When the engineer dials " 97 " from a subscriber's telephone and immediately replaces the handset, ringing current is automatically fed to that subscriber's line to ring the telephone bell. In this way the engineer can test the telephone bell without calling the test-desk engineer.

Facilities are provided at the test desk to allow the test engineer to test any line for earth, short circuit, or disconnection conditions. A normal line from the test desk to the M.D.F. enables the test engineer to make ordinary calls when necessary.

EQUIPMENT.

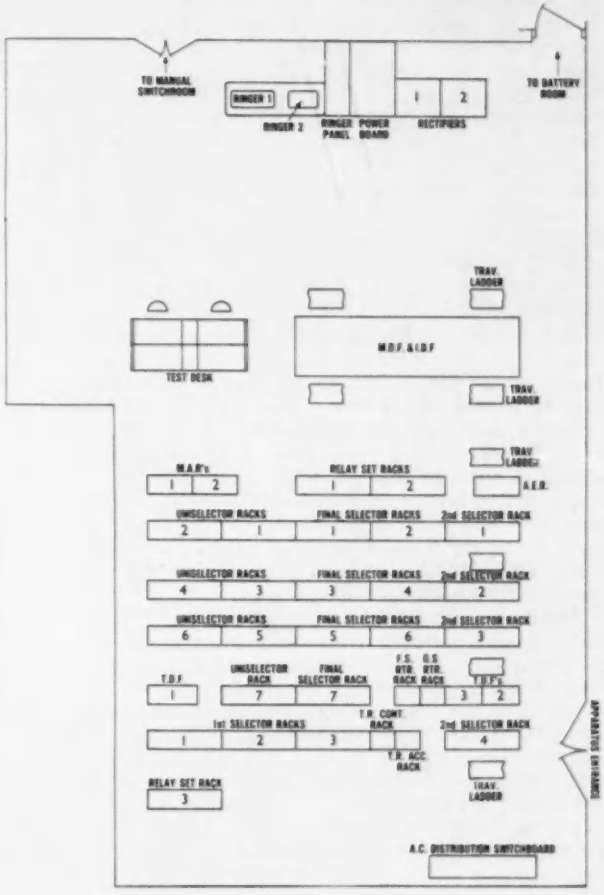
The equipment is mounted on standard racks 10 ft. 6 in. high (fig. 7). The line-circuit equipment is mounted on one rack, the final selectors on another rack, group selectors on another, and so on. The two-motion selectors used in Kuching are the SE50 type, designed specially by the G.E.C. for reliability and ease of maintenance. They mount on shelves, jack into position easily, and can be removed to a bench, if necessary, for adjustment or maintenance, without disconnecting any wiring (fig. 2).

Uniselectors of the latest design, which guarantees a long and trouble-free service life, are used in the subscribers' line circuits. Their compact construction allows 300 uniselectors, and their associated line relays, to be mounted on one rack, 4 ft. 6 in. wide. The relays used are the standard type in general use throughout the world for many years.

Subscribers' telephones are fitted with the G.E.C. trigger type dial in which the inter-digit pause before the pulses is provided by means of the trigger action.

A floor plan showing the arrangement of the equipment at Kuching is shown in fig. 8. It will be seen that the racks are mounted in suites, leaving adequate gangways down each side of the floor and between suites to give easy access to the equipment for inspection and maintenance. Travelling ladders are fitted in each apparatus gangway so that the equipment and terminal strips at the top of the racks are readily accessible. The ladders run on wheels and an overhead rail, and a brake device locks the ladder in position so that there is no chance of movement while an engineer is working on the ladder (fig. 7). Rack lighting is built into the overhead supports to provide illumination for both front and rear of the racks.

The test desk is installed in the apparatus room near the M.D.F., since access to the frame is often required during line testing. The manual switchboard is in a separate room opening off the apparatus room. The exchange operates on a 50 volt d.c. supply obtained from a battery of 24 lead-acid cells. Other rooms in the exchange provide space for a linesman's room, workshop and stores, and air-conditioning plant.



KEY

M.D.F.—Main distribution frame.
I.D.F.—Intermediate distribution frame.
M.A.R.—Miscellaneous apparatus rack.
A.E.R.—Alarm equipment rack.
T.D.F.—Trunk distribution frame.
F.S. RTR.—Final selector routiner rack.
G.S. RTR.—Group selector routiner rack.
T.R. Cont.—Traffic recorder control rack.
T.R. Acc.—Traffic recorder access rack.

Fig. 8.—Apparatus layout.

ACKNOWLEDGMENT.

The author gratefully acknowledges permission from the Posts & Telegraphs Department, Sarawak, to publish the photographs used in the above article.

New Substations in the London Area

INDUSTRIAL and residential development in London and the suburbs is making it necessary in many areas to augment facilities for the distribution of electrical power. New substations are being built, and increases in the capacity of existing installations are being accompanied by the provision of high-voltage connections with the grid system to replace locally-generated supplies. Substations therefore have to be built in a variety of different surroundings, and the problems encountered range from finding space for the equipment in congested areas, to designing buildings which will not clash with local domestic architecture and amenities in more spacious settings.

NEWINGTON HOUSE.

In Southwark a new bulk supply substation of the London Electricity Board has been housed in the basement and parts of the ground floor of Newington House, a modern six-floor office building recently opened to house the centralised accounts departments of the Board's South London area. Access to the substation is normally through an entrance in the Lancaster Street frontage communicating with an open yard for parking cars and cycles. The building was designed by the Board's architect, Mr. W. Mollison, F.R.I.B.A. Mr. A. Bailey, O.B.E., F.R.I.B.A., was the consultant architect.

Supplies to the substation are taken at 22 kV from Bankside and Deptford West Power Stations. Three 15 MVA, 22/11 kV transformers, on the ground floor of the building, feed the 11 kV busbars, from which fifteen outgoing feeders supply the Southwark area, where the loads range from heavy industrial plant to domestic consumers. Provision has been made for installing a fourth transformer at a later date.

The 22 kV and 11 kV switchgear and the control board for the substation were supplied by the G.E.C. In the 12-panel, duplicate busbar 22 kV switchboard the 500 MVA circuit breakers are arranged for vertical isolation by self-contained, motor-operated hoists. The beams which support each breaker form the rails on which it is traversed for connection to the front or rear busbars. The breakers in the 22-panel, 11 kV duplicate busbar board are rated at 250 MVA and also have vertical-isolation, but with hand-operated hoists. Each unit is mounted in a wheeled carriage which serves both for withdrawal and for traversing between busbars. All switchgear is solenoid-operated from a 110 V d.c. supply.

Fig. 1.—Newington House, Southwark.

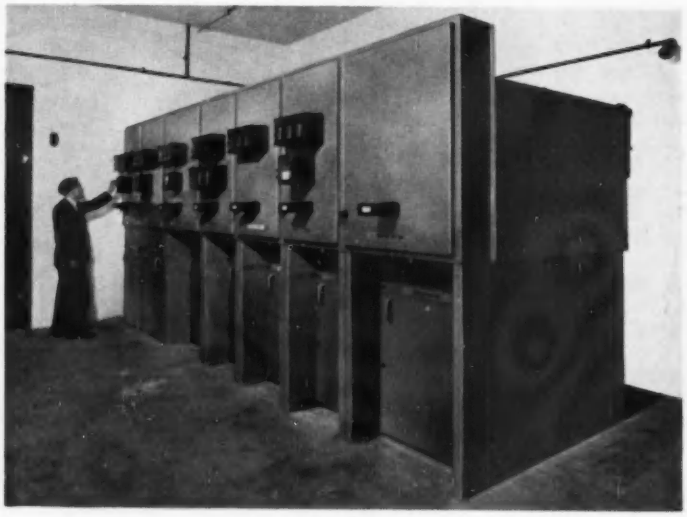


Fig. 2.—11 kV switchgear at Newington House.

All feeder and transformer units in the 22 kV board are equipped for core balance bus zone protection. Overcurrent, earth fault, Buchholz and winding temperature protection is afforded for the transformer units; and overcurrent and Beard Hunter protection for the feeder units.

The control board, on the first floor of the building, is provided with a mimic diagram showing the 22 kV and 11 kV switchgear, busbars and incoming and outgoing feeders. Indicator lamps are illuminated when the incoming feeders are alive although the corresponding circuit breakers may be open. All switchgear is operated from the board by means of discrepancy switches. Indication of busbar selection is also given by means of discrepancy switches.

Alarms are given by a bell and their nature is described on an illuminated fascia on the control desk. If the cause of the alarm is the automatic tripping of a circuit breaker, the corresponding discrepancy switch lamp lights up and a buzzer sounds in addition to the bell signal. In either case the bell is silenced by operating an "accept" button, but when a trip has occurred the control board lamp remains alight and the buzzer sounds until the board has been re-dressed.

The basement of the building accommodates the 22 kV and 11 kV main and multicore cables, heating services, strong room, etc.

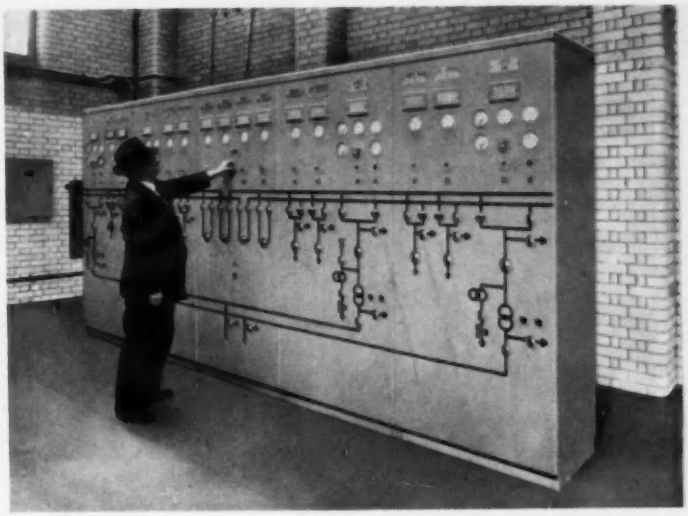


Fig. 4.—Mimic diagram board at Ley Street, Ilford, for remote control of switchgear at Perth Road.

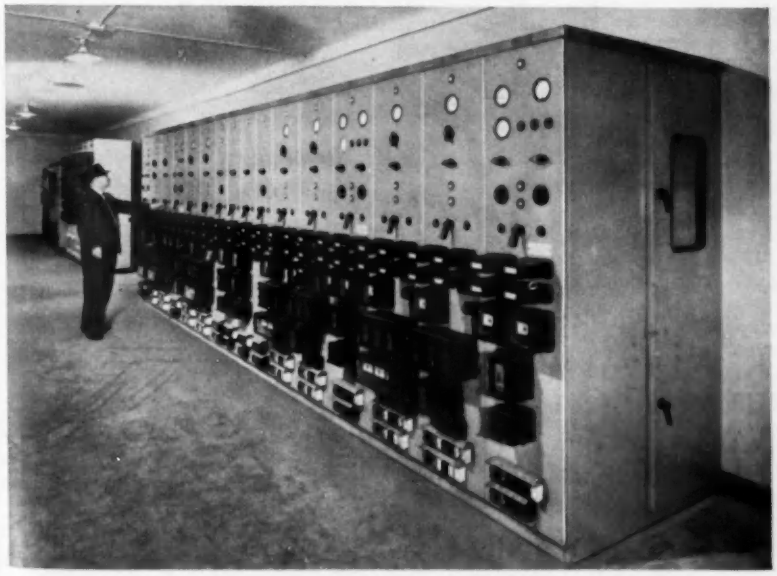


Fig. 3.—Relay and local control board at Perth Road, Ilford.

PERTH ROAD.

At Perth Road, Ilford, the 240 MVA substation of the London Electricity Board has the highest capacity of any substation in the London area on a site of comparable size. The site is opposite the Ley Street substation (originally the local power station for Ilford), and in the early days of electricity supply in the borough was occupied by various buildings and stores belonging to the power company. In 1927 a supply was taken from the County of London Electricity Supply Co. Ltd., and the first substation was built on the Perth Road site. Ley Street continued to generate and to operate rotary converters serving a large d.c. area.

Continuing growth of the Ilford and other networks in the area in recent years has made increased capacity necessary. A new substation was built at Perth Road in 1950 to receive a supply at 132 kV from the C.E.A. at Barking. Four 60 MVA, 132/33 kV transformers were installed and switch-

Fig. 5.—Harrow Grid Substation.

gear was provided for controlling 33 kV feeders to Ley Street, Clarks Road and Epping New Road.

A 16-panel, 33 kV, 750 MVA, duplicate-busbar switchboard, combined relay and local control board, and remote control board with mimic diagram were supplied for the new substation by the G.E.C. The switchgear comprises four units connecting the transformers to the busbars, three controlling feeders to Ley Street, three for the Epping New Road feeders, two for those to Clarks Road, two bus couplers, and front and rear bus section units. The remote control board, located at Ley Street, incorporates illuminated panels indicating the nature of faults, the occurrence of which is signalled by a bell, together with a buzzer and flashing of the discrepancy lamp concerned if a circuit-breaker has tripped. All the switchgear can be operated from the remote control board by discrepancy switches, but local control can be obtained at Perth Road after operating the appropriate local-remote switches on the relay board there.

HARROW GRID SUBSTATION.

To meet increasing demands in the Harrow and Northwood Districts of the Eastern Electricity Board, the supply at Harrow Grid Substation is now being taken from the Central Electricity Authority's 132 kV system via two 90 MVA, 132/33 kV transformers. These are connected to the four existing 33/11 kV transformers which were formerly supplied by Taylors Lane Generating Station, and serve local 11 kV substations in the two districts, while five 33 kV feeders go to more remote substations in the Northmet and Chilterns Sub-Areas.

A new 12-panel 33kV single busbar 750 MVA switchboard, relay board and control board at the substation have been supplied by the G.E.C. The switchgear is of the Company's metalclad type, with vertical isolation, and the two units controlling the 90 MVA transformers have the unusually high rating for 33 kV gear of 1600 amp. Discrepancy switches on the control board mimic diagram provide operation and indication of the switchgear and indication of when a unit is isolated and earthed.

The substation is situated in a residential area, with one frontage on a dual carriageway road. The design of the building housing the new 33 kV switchgear and control room conforms in style with the surroundings and with the earlier buildings on the same site. Small areas of lawn and garden have been laid out in front of the new building as a further contribution to preserving the character of the district.

The project was engineered and the building designed by the staff of the Eastern Electricity Board.

ACKNOWLEDGMENT.

In the preparation of this article valuable co-operation was received from the engineers of the London Electricity Board and the Eastern Electricity Board and their staffs, both in providing facilities for photography and in supplying information on the development and functions of the substations described.

Fig. 6.—The 12-panel 33 kV switchboard at Harrow.

Recent Applications of Infra-red Heating

By G. M. HOGARTH, B.Sc.,
Research Laboratories.

THE use of infra-red or radiant heating in manufacturing processes has expanded considerably within the last ten years. The stoving of paint —the process to which infra-red heating was first applied—is still the most widespread application, accounting for some 40 per cent of the installations. More recently, however, infra-red heating has been utilised for the treatment of plastics, rubber and textiles and for other interesting applications. The main advantages of this form of heating compared with other methods which are used for similar processes are that high rates of heating are obtained and treatment times are comparatively short.

In infra-red heating the transfer of energy from the high-temperature source to the object or material being heated does not depend on the temperature of the surrounding air—as in convection heating—but mainly on the temperature of the source. The output of energy from a source increases rapidly as its temperature is raised ; this radiation output is, in fact, proportional to the fourth power of the temperature.

Other factors affecting the energy output of the source are its emissivity and its area. The amount of radiation is directly proportional to the area of the source. Thus small sources at high temperatures or large sources at lower temperatures can be used to give the same radiant output.

Of two sources commonly used for infra-red heating, one operates at a temperature of about 700 deg. C. and the other at a temperature of 2200 deg. C. The radiation from each is arranged to be comparable in intensity but there are important differences in the quality of radiation. Most of the energy radiated by the lower temperature source is in the wavelength band 2·5 to 7·0 microns, whereas that from the higher temperature source is in the shorter wavelengths from 0·8 to 2·5 microns, with the peak emission at 1·1 microns.

Many of the materials commonly heated respond differently to the different wavelengths of radiation. Various coloured paints absorb different amounts of the shorter wavelength radiation ; a matt black finished panel, for example, will heat up 30 per cent more rapidly than a glossy white panel under the same conditions. These differences are hardly noticeable when the longer wavelength radiation is used ; all colours absorb the incident radiation at about the same rate, and the same heating time can be used for the different colours.

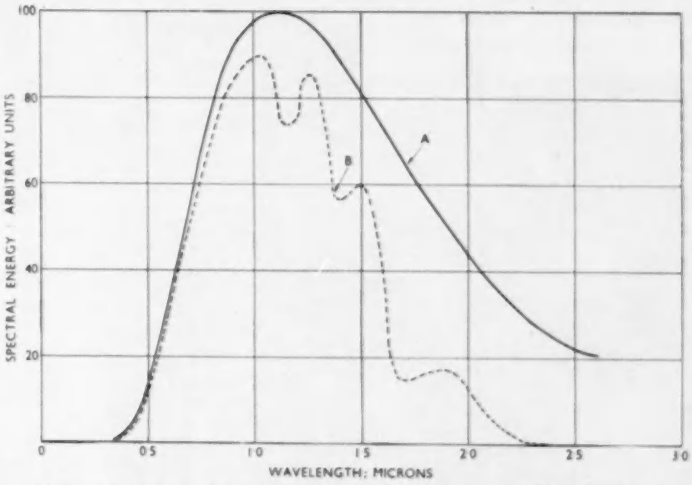


Fig. 1.—Curves showing (a) spectral energy distribution of radiation emitted by an infra-red lamp[1] ; (b) distribution of proportion of it which is transmitted through 0·1 in. thick clear uncoloured acrylic-sheet.[2]

The selective absorption of radiation of different wavelengths by another material, " Perspex ", is illustrated in fig. 1. The curve *A* shows the wavelength distribution of the energy from a high temperature source, and curve *B* the energy transmitted through a thin sheet at different wavelengths. Whereas the shorter wavelengths are transmitted fairly readily, radiation having a wavelength greater than 2·5 microns is completely absorbed and would result in surface heating. Thus, in heating sheets of " Perspex ", where there is an advantage in through-heating the material, the shorter wavelength radiation is preferred.

Selective absorption also takes place in water.

Radiation of wavelengths 3·0 and 6·0 microns is strongly absorbed, but water is relatively transparent to shorter wavelengths. For this reason it is often considered that the longer wavelength sources are more efficient when used for evaporating moisture. In the majority of these processes, however, the film of water is so thin that the heating, and therefore the evaporation, depends to a much greater extent on the properties of the underlying surface. If these surfaces are good absorbers of both long and short wavelength radiation then it is immaterial whether the hot source is operating at high or low temperature.

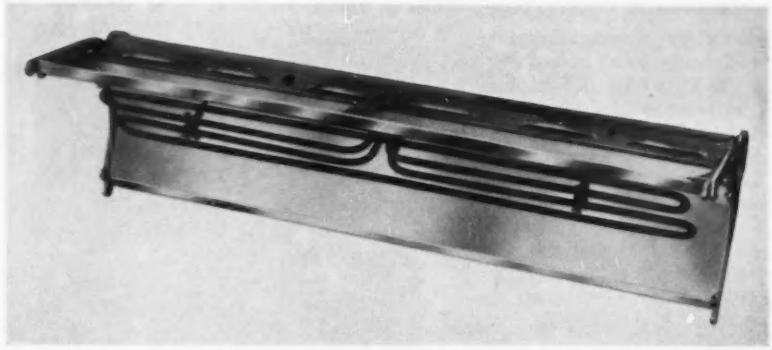


Fig. 3.—Standard 3 ft. sheathed wire element reflector unit.

Fig. 2.—Osram 250 watt infra-red reflector lamp.

Typical examples of standard infra-red heating units are shown in fig. 2 and 3. The reflector lamp, fig. 2, has a coiled tungsten filament rated at 250 watts and operating at 2200 deg. C. The lamp has an internally silvered surface to direct the radiation forward on to the work. In normal use a life of 5,000 hours may be expected. An advantage of the use of lamps is that, on switching on, the filament reaches its operating temperature almost instantaneously and the full output of a lamp oven is immediately available.

The reflector unit shown in fig. 3 incorporates sheathed wire elements operating at 650 deg.-700 deg. C. These units are very robust and are widely used for paint stoving. They also have a long life and low maintenance cost.

A disadvantage of most low temperature sources is their high thermal capacity. This results in a relatively long heating up or cooling down time. In some applications, such as the treatment of paper or textiles, this may constitute a source of danger in the event of an accidental stoppage and special precautions have to be taken to remove the heat source or to shield the work from the radiation in such circumstances.

In all radiant heat ovens the source temperature is much higher than the maximum temperature of the treatment. Close control is needed, therefore, to avoid spoiling the article by overheating. It is more usual to control the time than the temperature especially as, with a moving article, the latter is often impractical.

Applications of infra-red heating to industrial processes include paint stoving, softening thermoplastic sheet, and curing plastic coatings and glass-reinforced resin structures. A particularly interesting application is the testing of aircraft structures at elevated temperatures.

PAINT STOVING.

During the war, widespread use was made of infra-red heating for the stoving of paint on ammunition boxes, jerricans and shells. Since then, ovens have been installed to stove paint on a wide range of articles varying from small components used in telephone selector racks to heavy tank parts weighing several hundredweight.

A problem which frequently arises is the stoving of paint on metal parts of different sections. Careful positioning of the article within the oven, in combination with a paint having a wide stoving tolerance, will frequently provide a satisfactory answer. A paint material having suitable properties is based on styrenated alkyd resin. A recent example of such application is in the finishing of agricultural machinery in which both heavy castings and light sheet metal components are used.

An L-shaped infra-red oven (fig. 4) built up of sheathed wire element reflector units is used to stove the finish on a gearless side rake and swath turner, shown being wheeled into the oven. The electrical loading of the oven is 84 kW and the time required to stove the finish is 6 minutes, but some of the heating units are

switched off automatically after 4 minutes. The vertical units at the end of the oven and on the hinged door are arranged to stove the paint on particular parts of the machine. Other heating units, situated within the oven, stove the paint on various parts of the tubular framework. This ability to project heat exactly where it is required is one of the main advantages of radiant heating. Although the machine shown has rubber tyres, it has not been found necessary to take any special precautions to prevent their overheating.

Fig. 4.—Sheathed wire element oven used to stove the finish on agricultural implements.

Sheets of polished aluminium are used to enclose the oven as much as possible. This is done partly to use any stray radiation, by multiple internal reflections, but mainly to prevent draughts from blowing through the oven and cooling the article being heated.

In addition to the oven illustrated, the same factory has two other infra-red ovens for stoving the primer and finish on various other components.

SOFTENING OF PLASTIC SHEET.

Many of the plastics used in the manufacture of household and other articles are produced on high-pressure presses using either the injection or compression moulding technique. Others, however, are fabricated from sheet, previously softened, using either low pressures or a vacuum to blow or draw the sheet into the mould.

Infra-red heating has for some years been used for the softening of thermoplastic sheet such as "Perspex", polystyrene, polythene and rigid p.v.c. As a result of the complete absorption of long wave radiation by the surface layers and the consequent tendency for sheets of $\frac{3}{16}$ in. thickness and over to blister, it has been found impractical to use low temperature radiant heaters for such thicknesses at a sufficiently high intensity to be economic. However, thermoplastic sheet, unless heavily pigmented, is semi-transparent to the short wave radiation emitted by lamps. A certain degree of through heating can be achieved and intensities up to 2 kW/ft.^{2} may be used for softening sheets up to at least $\frac{1}{4}$ in. thick. This can be done without risk of overheating the surface before the sheet has become soft enough to mould. The graph in fig. 5 gives the softening times for clear uncoloured "Perspex", the moulding temperature of which is 160 deg. C.

Many aircraft are fitted with cockpit canopies and observation nosepieces fabricated in "Perspex". These components have to pass stringent optical tests for clarity and freedom from distortion. The cockpit canopy and nosepiece for the "Canberra" bomber are fabricated from sheets of "Perspex" up to 8 ft. square. Fig. 6 shows a nosepiece being inspected; the lamp oven in which the sheets are softened can be seen in the background.

Many forms of lighting fitting are also moulded in "Perspex". Fig. 7 shows some typical examples. In fig. 8, the oven again incorporates reflector lamps and

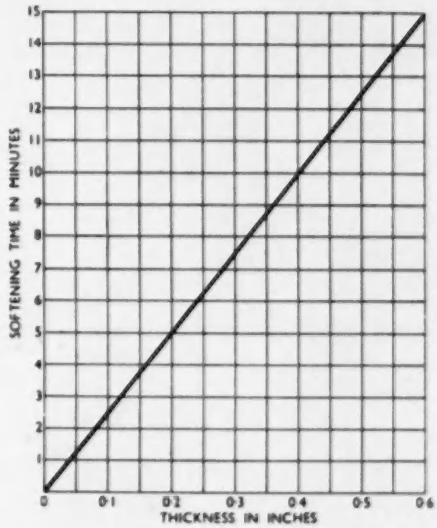


Fig. 5.—Softening times for clear "Perspex" using a single horizontal bank of infra-red reflector lamps.

is divided into sections, each individually controlled. Several small sheets can thus be softened simultaneously but for varying periods according to thickness. The total electrical loading of this oven is 48 kW.

Another use of infra-red heating for the softening of thermoplastic sheet is in the manufacture of orthopaedic appliances such as limb supports and spinal jackets. The splints are made up of a laminate of polythene and foamed polyurethane, both of which are light, resistant to moisture and acids, and practically non-inflammable.

The method of manufacture is simple and quick. A sheet of foamed polyurethane is laid on the asbestos bedplate of an infra-red lamp oven (fig. 9). A sheet of cleaned polythene is then placed over this and the combination is heated, from above, by a horizontal bank of lamps. A slow rate of heating has been found to be desirable and the lamps are either operated at a reduced voltage or the oven is fitted with an energy regulator which switches the lamps on and off to give a predetermined low average heat output. After some 15-20 minutes, the temperature of the polythene reaches 130 deg. C., when it becomes transparent and adheres firmly to the underlying sheet of polyurethane.

A piece of stockinet is then placed over the polythene and the whole lifted from the oven and applied either directly to the patient or, in the case of large splints, to a plaster cast. The stockinet enables the laminate to be moulded accurately to the contours of the patient or the cast. On cooling, the stockinet is stripped from the polythene and the splint removed. The edges are trimmed and ventilation holes punched in the appropriate places. The finished splint (fig. 10) has a slight resilience at body temperature. A neck support made by this method from a positive cast can be supplied to the patient in two and a half hours.

Fig. 7.—" Perspex " lighting fittings.

Fig. 6.—A " Canberra " nosepiece being examined after moulding.

THE CURING OF P.V.C. AND SYNTHETIC RUBBER COATINGS.

The production on a large scale of rubberised fabrics, p.v.c. belting for the coal-mining industry, needleloom and other rubber or plastic backed carpeting has necessitated the development of a suitable means for curing rapidly the various coatings.

The gelling, or curing, of coatings of p.v.c. paste and synthetic rubber at temperatures ranging from 100 deg. to 170 deg. C. is an application for which infra-red heating is well suited. The paste is applied to the fabric by means of rollers or a doctor knife in thicknesses not normally greater than $\frac{1}{16}$ in. although coatings up to $\frac{1}{8}$ in. thickness are applied in special cases.

Synthetic coatings are partly transparent to the short wave radiation from lamps whereas the longer wavelengths emitted by sheathed wire elements are almost completely

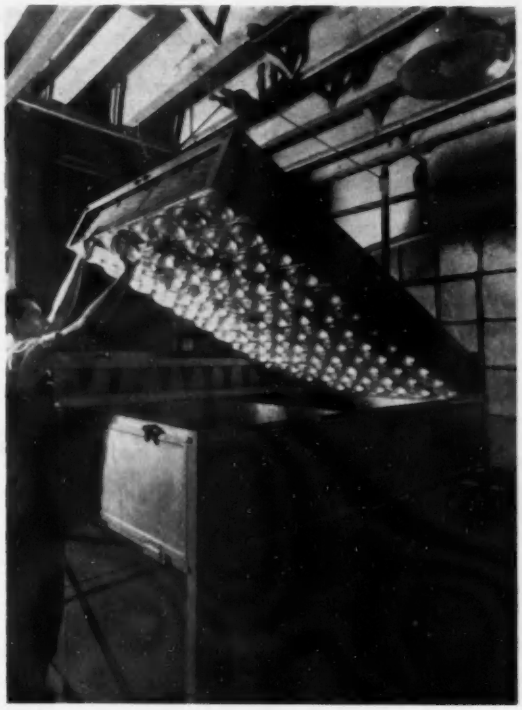


Fig. 8.—An infra-red lamp oven used to soften thermoplastic sheet preparatory to being moulded into lighting fittings.

absorbed even by thin coatings. For this reason it is usually more economical to use ovens incorporating sheathed wire elements operating at a temperature of 650 deg. to 700 deg. C.

Special heating panels (fig. 11) have been developed for the treatment of continuous coatings on fabric and other surfaces. The elements are arranged at an angle to the direction of travel, to avoid any tendency to produce uneven heating. If this is not done, and the elements are arranged parallel to the direction of travel, a pattern of over- and under-heated stripes, corresponding to the position of the elements, results. To compensate for the cooling effect at the edges of the material, resulting from draughts and the presence of heavy structural members, the outer elements have a higher loading than those at the centre. A backing reflector of polished aluminium is used to direct the radiation on to the heated surface.

As mentioned previously, the thermal capacity of the sheathed wire element is high, and should there be an accidental stoppage during the process, the material within the oven would overheat and be damaged and may even cause a fire. To overcome this possibility, it is arranged that, in the event of a stoppage, not only is the oven switched off but it is also raised bodily to a height of at least 2 ft. above the material. Several ovens of this type have recently been supplied to manufacturers of conveyor belting for coal mines and of needleloom and tufted carpeting.

Another recent application of the gelling of p.v.c. by infra-red heating concerns the provision of protective coverings for machined components. The component is heated to a temperature of 160 deg.-170 deg. C. in a suitably shaped infra-red oven built up of sheathed wire element units. It is then dipped into a tank of p.v.c. paste for a predetermined period, depending on the coating thickness required, and replaced in the oven for the final curing operation. On a small sample casting the process time using infra-red heating was 30 minutes compared with 2 hours in a convection oven.

Fig. 9.—Lamp oven used in the manufacture of orthopaedic appliances.

Fig. 10.—The final stages in the manufacture of a spinal jacket.

TREATMENT OF NYLON AND OTHER FABRICS.

With the development of synthetic fibres such as nylon, " Terylene " and " Orlon " came the necessity for the application of a suitable heat treatment to the finished fabric so as to render it dimensionally stable and resistant to permanent creasing during, for example, scouring and dyeing or ordinary hand-washing of made-up garments. This heat treatment, termed " setting ", also improves the " handle " and " drape ".

The fibres which respond to the setting process are all thermoplastic ; nylon, for example, melts at 263 deg. C. Nylon fabric may be set by using steam at 120-140 deg. C. or by dry heat at a temperature of 190-220 deg. C.

One difficulty which can occur during the setting process is the oxidation of the fabric. This not only discolours the material but also results in a reduction in physical strength. The use of a steam atmosphere overcomes this problem but the length of time taken for processing and the lack of control over the dimensions of the fabric have restricted its use. There are two main methods of dry heat setting, one using hot gas and the other infra-red heat. The disadvantage of the first is that, at the high temperatures used, even a small amount of oxygen present in the gas will cause oxidation. The oven itself is generally a large and expensive item and it is not yet possible to set fabrics after they have been dyed. With infra-red heating, on the other hand, the short process times and still air conditions in the oven reduce oxidation to a negligible quantity. The ovens are light, compact and may be easily adapted to existing finishing lines. Another advantage is that the fabric may be set after being dyed.

Before setting, the fabric is scoured in a dilute solution of soap and soda ash and dried. It is then fed to a machine called a stenter. This consists basically of two parallel moving chains with pins mounted, points upwards, in the links. These pins engage the edges of the fabric and control its dimensions during the heat treatment. The heater panels are similar to those used for the gelling of p.v.c. paste and are built in various sizes to handle the standard widths of fabric. The setting time varies according to the fabric weight, being 8-10 seconds for nylon fabrics in the range 1-2 oz./sq. yd. and 25-30 seconds for fabrics weighing 10-12 oz./sq. yd. Once a fabric has been set it will, unless taken above the setting temperature, retain the shape given to it during the heat treatment, whether this was flat or in the form of pleats as in a skirt.

Care is needed when ironing garments made from fabrics set by heat, to ensure that the iron is not too hot, otherwise, even if the fibres do not melt and stick to the iron, the garment may be pulled out of its original shape and set in a new one.

During the heating process, the fabric temperature rises rapidly, at a rate up to 20 deg. C./second, and it is important, therefore, that the process time and the oven temperature are held within fine limits. The heating time is dependent on the conveyor speed, which in turn is held reasonably constant by the drive motor. The oven temperature is controlled by a thermocouple attached to a small metal foil plate situated in close proximity to the heating element. The signal from the thermocouple is fed to a temperature controller having a control sensitivity better than ± 1 deg. C. The controller then switches the oven between two heat levels, one above and one below the control point. The temperature of the fabric is held within ± 8 deg. C., a tolerance found in practice to be satisfactory.

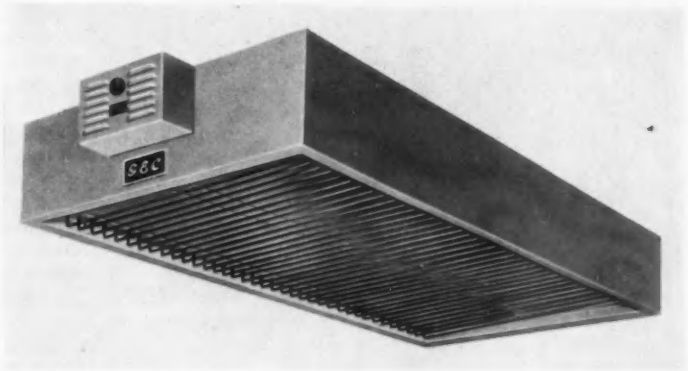


Fig. 11.—A sheathed wire element reflector panel used for the curing of plastic coatings and the treatment of fabrics.

THE CURING OF GLASS-REINFORCED PLASTICS STRUCTURES.

The use of glass-reinforced plastics is becoming more widespread every day, as for example in the construction of boats up to 56 ft. in length, piping up to 6 in. diameter, aircraft radomes and hot-air ducts, omnibus and caravan panels, complete motor-car bodies and numerous components for use in the electrical industry. Infra-red heating is used in all these applications to reduce the curing time of the resin.

It has been known for many years that the properties of some plastic materials could be enhanced by reinforcing them with cotton, asbestos fibres and inert powders, but only recently has it become economical to use glass fibres as reinforcement. Earlier attempts to use them were disappointing, for the only resins available required a high moulding pressure which crushed the glass fibres. These were also relatively expensive.

During the last war, resins of the polyester type were developed which could be cured without the application of pressure. Thus, it became possible to use glass fibres as the reinforcing medium. These fibres have a high tensile strength, are completely fireproof, resist biological attack, chemicals and weathering, are dimensionally stable and have a high heat resistance.

Many of the resins will cure at room temperatures by the addition of a catalyst. At these temperatures, however, the process may take some hours, and can be greatly accelerated by the application of heat in the form of hot air or infra-red lamp radiation. The latter is easily controlled, may be focused on a particular area and there is a through heating effect resulting from the penetrating power of the short wavelength radiation emitted by the lamps.

An oven which is used to cure glass/polyester resin components has been installed by Berkeley Coachwork (Sales & Export) Ltd., the maker of the Berkeley sports car. The body of this car, which has attracted considerable attention, is constructed almost entirely of glass fibre reinforced polyester resin, the curing of which caused delays in the production line. To speed the process, an infra-red lamp oven was installed. This has been a complete success. Even the thickest sections, up to $\frac{1}{4}$ in. in thickness, are evenly cured with no risk of overheating the surface. The body consists of nine mouldings, produced on moulds which are themselves made of polyester resin/glass fibre.

The sequence of operations on the production of a moulding is as follows :

A gel coat, which forms the outer skin, is applied first. After curing, layers of glass chopped strand mat are placed on top and the whole impregnated with polyester resin. This is then cured, after which the moulding has the various metal components resin-bonded in place. A third application of heat is made to cure the bond.

The three curing operations are carried out in a rotary infra-red oven. A spindle with a horizontal axis and having positions for four mouldings, rotates within an enclosed space underneath banks of infra-red reflector lamps radiating downwards on to the mouldings.

The spindle is rotated 90° every 15 minutes so that after one revolution each moulding has received a 60-minute cure. The present output is 100 cars a week.

THE TESTING OF AIRCRAFT STRUCTURES AT ELEVATED TEMPERATURES.

With the advent of supersonic flight, aircraft designers have to face the problem of skin heating caused by the friction of the air as it passes over the aircraft surfaces. These must be capable of withstanding not only steady high temperatures but also the transient thermal stresses produced during the climb to high altitudes. Some idea of the problem may be obtained from the fact that at a speed of Mach 2 and an altitude of 50,000 ft. the surface of an aircraft will attain a temperature of about 100 deg. C. At a speed of Mach 2 and an altitude of 30,000 ft. the temperature would rise to 150 deg. C.

Power inputs as high as 100 kW/ft.^{2} are needed to produce these temperatures quickly and one method of simulating these conditions in the laboratory is to subject the test piece to infra-red radiation emitted either by carbon rods or tungsten filament lamps.

Carbon rods, arranged in banks with a suitable reflector behind them to direct the radiation on to the test surface, are electrically heated to about 2500 deg. C. A disadvantage of the carbon rod is its thermal inertia which reduces its usefulness in applications where it is necessary to vary the heat output rapidly during test. This difficulty may be overcome by the use of a new design of tungsten filament lamp, consisting of a single-coil tungsten filament in a quartz tube 13 in. long and 11 mm. in diameter. The filament is supported along its length by molybdenum discs and power is supplied to it via nickel end caps. The lamp is rated at 100 watts per inch, at which rating the life is about 5,000 hours. To obtain the high heating rates required for aircraft testing, the lamps are operated at double the rated voltage with a consequent trebling in power. In these conditions the life is, of course, reduced considerably. The lamps attain at least 70 per cent of their output within one second of switching on and their rapid response to changes in supply voltage makes them readily adaptable to heating programmes requiring complex time/temperature distribution. Two rows of lamps per bank are used, the lamps in the rear being staggered to radiate between those in front.

In this article only some of the more interesting applications of infra-red heating have been described. There are many others—for example, the drying of printing inks and lacquers, and moisture evaporation. Radiant heating is being used more and more in industry to-day and this increase will continue as the demand grows for shorter process times and more compact equipment.

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Signalling on Low-level Lines in Glasgow

By A. N. McKILLOP, A.M.I.R.S.E.,
Siemens and General Electric Railway Signal Co. Ltd.

IN 1888 the former Caledonian Railway obtained powers to build a suburban line in Glasgow from Rutherglen to Kelvinbridge and Maryhill, with a connection at Stobcross for Partick and beyond. For some five miles between Dalmarnock and Stobcross the line is underground ; on this section it has its own platforms below Glasgow Central station, and for this reason the route and its immediate connections are generally known as the Glasgow Central Low-level lines (fig. 1).

cabins and re-equipping completely the two tunnel section signal cabins which have been retained at Stobcross Junction and Bridgeton Cross Junction. A contract for this work was placed with The Siemens and General Electric Railway Signal Co. Ltd. by the Scottish Region of British Railways.

TRACK-CIRCUITS.

The resignalling, which is now in service, extends over the 6¾ miles between Partick and Strathclyde

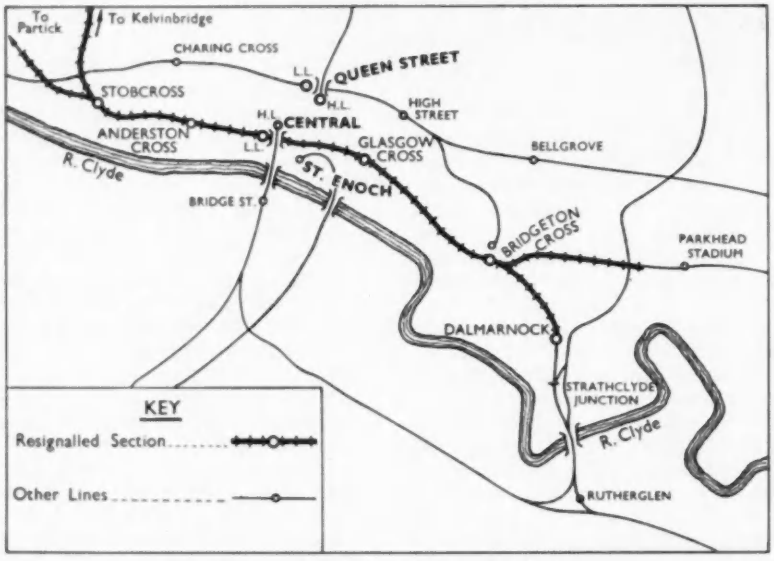

Fig. 1.—Resignalled section of Glasgow low-level lines.

The lines are steam-worked, and with the original semaphore signalling the sighting of signal indications in the underground section was often rendered awkward by smoke and steam. In the confined surroundings of the tunnel, also, the maintenance of equipment and care of signal lamps were carried out under difficulties, while the smoke-laden atmosphere adversely affected the life of fittings.

To improve these conditions, it was decided to equip the underground section with modern colour-light signalling, at the same time closing six signal

Junction (Dalmarnock), the whole of this section being controlled by multiple-aspect colour-light signals with continuous track-circuiting. There are 56 double-rail condenser-fed a.c. track circuits. In the tunnel the rail surface may become very dirty, with consequent risk of loss of shunt. A special feature has therefore been incorporated in the operation of the track-circuits, so that after a track-circuit has been occupied it cannot clear again electrically until the next one in advance has been proved occupied. Basically, the arrangement is that once the first track

relay has been de-energised by the presence of a train, its local coil remains without power until a back contact of the second relay has been made. The first relay then picks up and is allowed to be held over

Fig. 2.—Three-aspect colour-light signal with spreadlight lenses for wide-angle indication at short range.

one of its own contacts. This method is not applicable where a train does not proceed into the section ahead but has to be shunted back. In such circumstances the actuation of the relevant shunt signal is used to enable the track-circuit to be restored to normal at the right time. The principle is applied with various modifications according to particular requirements and is extended to fulfil other functions, such as proving that a signal is " on " with the lamp filament intact, and that the detonator placer (associated with all running signals as described below) has operated correctly.

Precautions are also incorporated against the effects of a power failure, which, if of sufficient duration, would result in all relays fed from the same source being de-energised together. A slow-to-operate characteristic has therefore been introduced into certain relays to ensure that all pick up in the correct sequence when power is restored, the effect being that the picking-up of such a relay is delayed until the one relating to the section in rear has been duly energised.

RUNNING AND SHUNT SIGNALS.

There are 26 main running signals, with two, three, or four aspects as required. At facing junctions five-lamp route indicators are mounted above the signals. Four of the signals are normally fully automatic. The remainder are for the most part semi-automatic, capable of being controlled from panels either at Bridgeton Cross Junction or Stobcross Junction cabins. Splitting approach repeater signals are provided in rear of the junction signals at these two places. The Bridgeton Cross repeater is a bracket signal with aspects arranged to serve as an outer home for the junction signal as well as giving the splitting indications. When a running signal is placed low down, the red aspect is shown from the top lens so as to be close to driver's eye level. Spreadlight lenses are fitted to signals which have to be viewed from close range, as shown in the illustration, fig. 2, of the signal controlling the exit from the sidings at Bridgeton Cross. The 18 ground-shunting signals are two-aspect position lights, their normal aspect being a red and a white light horizontally, while " proceed " is shown by two white lights at an angle of 45°.

Aspects in the main running signals are illuminated by transformer-fed 12 V, 25 W S.L.17 lamps and the junction indicators by 110 V, 25 W focus type lamps. The shunting signal lamps are 110 V, 25 W.

DETONATOR PLACERS.

Twenty-two detonator-placers have been installed immediately in advance of main running signals, as a precaution against signals being missed in bad visibility. For this purpose standard S.G.E. signal machines (fig. 3) have been used in modified form, operated on the 110 V a.c. signalling supply through

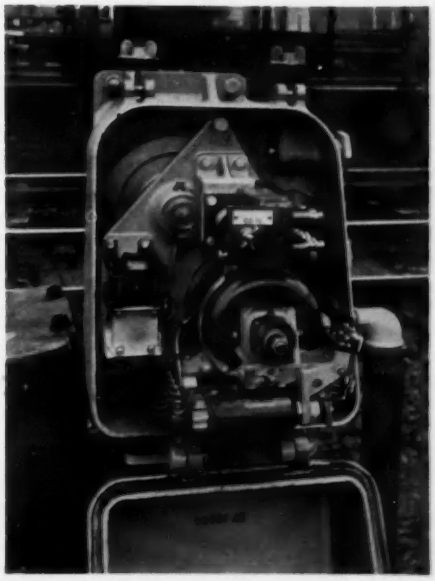

Fig. 3.—Interior of signal machine operating Bridgeton Cross down distant semaphore.

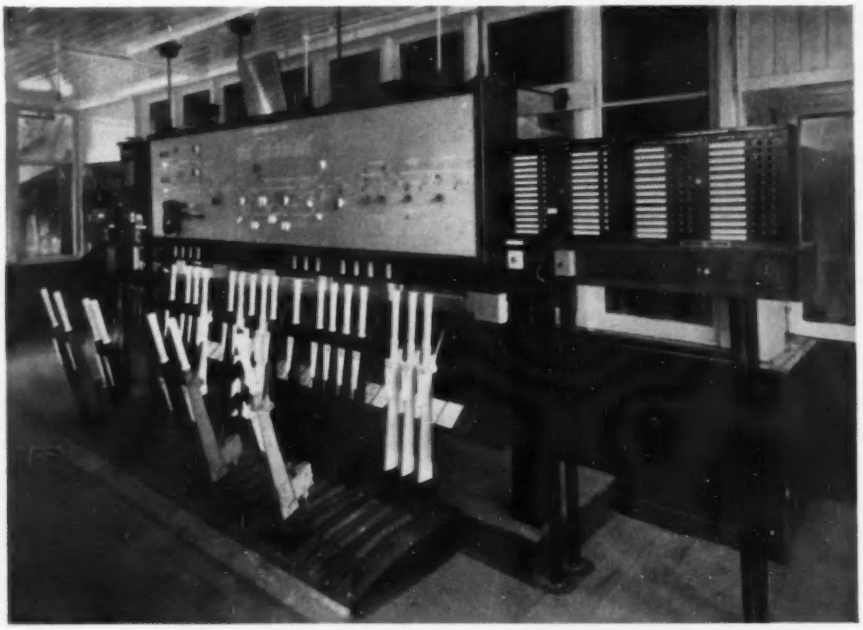

Fig. 4.—Panel for operation of signals mounted above point lever frame at Stobcross Junction.

a transformer-rectifier unit housed inside the signal machine case. Operation is entirely automatic, the detonators being lifted off the rail by the action of clearing the associated signal. A hold-off coil is energised to latch the mechanism against the effect of the balance weight when the detonators are clear of the track. Release of the latch by restoration of the signal to "danger", or in the event of an electrical failure, allows the weight to fall and replace the detonators on the rail.

SIGNAL CABIN EQUIPMENT.

Stobcross Junction and Bridgeton Cross Junction signal cabins have been completely re-equipped and each provided with a control panel mounted above a mechanical lever frame (fig. 4 and 6). Each panel presents an illuminated diagram on which thumb switches are mounted in the positions corresponding to the location on the track of the signals they control. Magazine type train describers are installed for working between these cabins. Block commutators and indicating lamps are mounted on the panels for working between Stobcross Junction and Partick Central, and between Bridgeton Cross Junction and Strathclyde Junction. The panels are of Warerite with the diagram lines processed into the surface in various colours on a green background to avoid glare.

Points are operated mechanically from the lever frames, with electric interlocking between the panel switches and the levers through electric lever locks and circuit controllers (fig. 5).

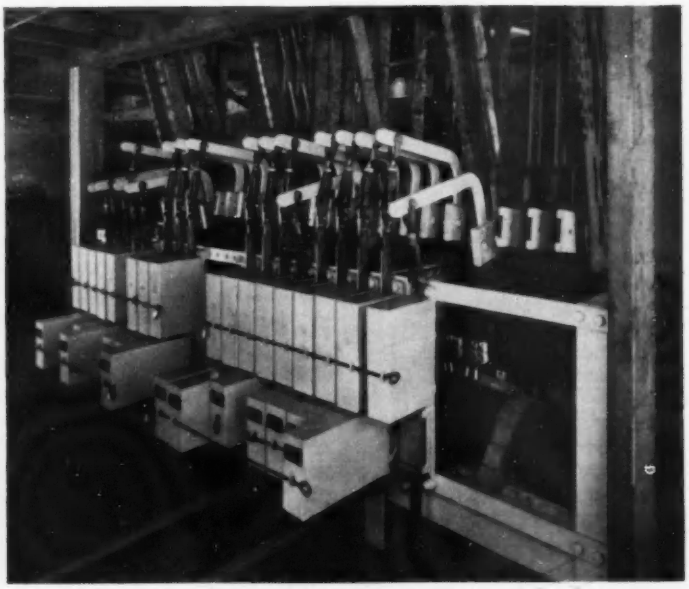

Fig. 5.—Electric lever locks and circuit controllers on lever frame at Stobcross Junction.

RELAYS AND POWER SUPPLIES.

Track relays are of the double-element, two-position a.c. type, 110/2 volts, 50 c/s, with four front and two back contacts. Line relays also operate from a 110 V a.c. source, but incorporate rectifier-transformer units mounted on their bases so that the relay coils are energised by low-voltage d.c., but are immunised from stray d.c. by the isolating effect of the transformer. The d.c. relays in the installation operate on 24 V. All relays, both in outside locations and in the relay rooms, are of the plug-in type, and fitted with terminal boards mounted in the rear to facilitate testing.

Signalling power originates in two 240 V a.c. single-phase feeders supplied from different parts of the supply authority's network. These feeders are brought into automatic transfer equipment which, in conjunction with a diesel-generator set, automatically ensures continuity of supply under all conditions by transferring the load, in the event of public supply failure, from the preferred to the alternative supply, and, if that, too, has failed, to the diesel-generator set. From the transfer equipment the main feeder extends to duplicate main transformers which step up the voltage from 240 to 650 V. At this voltage the supply is distributed by independent cable to each lineside location, to the two signal cabins at Stobcross and Bridgeton Cross, and to the outlying signal cabins at Parkhead, Strathclyde, Kelvinbridge and Partick Central. At each of these points the voltage is stepped down from 650 to 110 V by a location transformer in a specially-marked location case, and feeds the local apparatus.

TELEPHONES.

The contract awarded to S.G.E. included the supply of all signal post telephone equipment, including central batteries and chargers. The telephones are housed in watertight steel cases at every main running signal. An illuminated identification sign and telephone sign is provided at every such signal in the tunnel section. When Bridgeton Cross Junction and Stobcross Junction signal cabins are closed the signal post telephones are switched, up and down lines independently, to Strathclyde Junction signal cabin, which is always open and has communication with the next signal box which is open at the other end of this section of line.

ACKNOWLEDGMENT.

Acknowledgment is made to Mr. L. J. M. Knotts, Signal Engineer, Scottish Region, for permission to publish details and photographs of the installation and to the Public Relations and Publicity Officer, Scottish Region, for assistance in preparing this article.

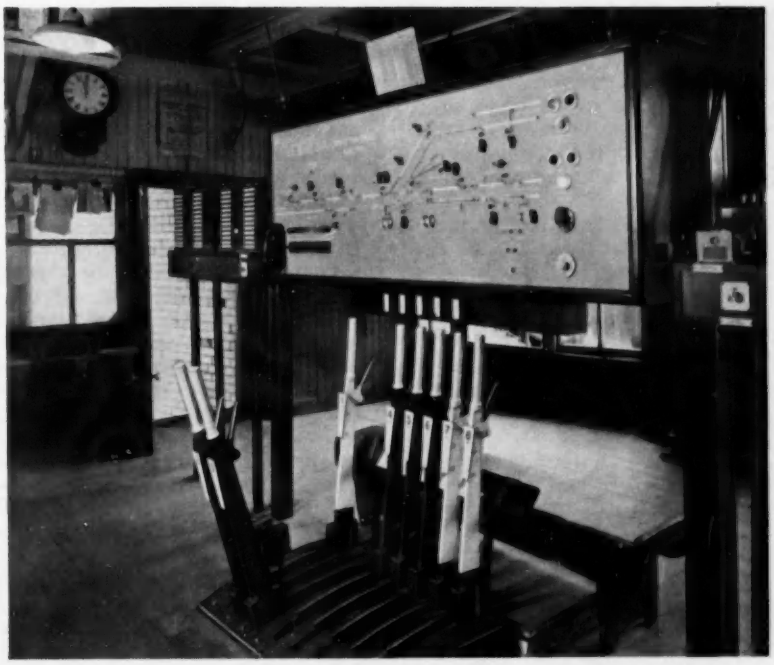

Fig. 6.—Panel above lever frame at Bridgeton Cross Junction, showing block commutator and indicating lamps on right.

Further Developments in the Design and Ventilation of Large Turbo-Alternators

By V. EASTON, B.Sc., A.M.I.E.E.,
Witton Engineering Works.

Now that manufacturers are called upon to build individual generating units of over 200 MW capacity, they are faced with the problem of keeping stator weights within the limits imposed by transport considerations which in this country restrict the weight of a single load to about 150/160 tons.

In this article the author explains how this problem has been solved by direct-cooling the stator windings and describes a method developed by the Company which entails minimum interference with established methods of stator construction.

IN a recent article in this Journal[1] an account was given of the arrangement developed by the Company for direct cooling turbo-alternator rotor windings, which has resulted in the lifting of a fundamental limitation in design and has led directly to a large reduction in frame size, or, alternatively, an increase in the possible rating of a single unit running at 3,000 r.p.m. The advantages to be gained from a similar improved heat dissipation from the stator conductors is much less marked since primarily it will affect only the proportions of the slot, permitting a reduction in core diameter and, therefore, in physical size but giving no increase in the specific output. The design of large units is, however, also influenced by other somewhat artificial limitations such as the maximum permissible transport weight of a single item, which in this country is of the order of 150/160 tons. While it is entirely practicable to build a G.E.C. conventionally-cooled stator having an output in excess of 200 MW within this figure, for the larger units now under consideration direct cooling of the stator windings is essential as one means of reducing weight. Below this output the additional complication can hardly be justified.

In the development of the direct cooled stator, the same guiding principles have been adopted as in the rotor design. These are first, that the final arrangement must satisfy mechanical as well as electrical requirements; secondly, the disturbance to well established methods and practices in manufacture should be as small as possible; and, thirdly, the modifications required and any new techniques should be exhaustively tested by constructing models of various parts or by other suitable means. An essential feature of the last-mentioned requirement is close consultation with the several shop superintendents from an early stage and the making of any models in the production shop, not only to obtain the benefit of practical experience but also to familiarise the craftsmen concerned with any modified techniques before they are required to produce the complete machine.

CHOICE OF COOLANT.

In comparison with rotor direct cooling, some problems associated with the application of the same principles to stator windings are more difficult. For example, on the rotor the excitation voltage is relatively low, parts of the windings are normally uninsulated and in the design described in the previous article there is no difficulty in arranging suitable gas entry and exit ports in the conductors. Again, there is no serious electrical limitation on the size of individual conductors and by adopting a suitable section, a duct of good aerodynamic shape can be obtained. On the stator, the voltage is much higher, bare metal is unacceptable and special precautions must be taken in insulating the points at which the coolant is led to or from the windings. Furthermore, the size of individual strips or laminations making up the conductors should be limited to avoid excessive eddy current losses resulting from the a.c. currents which they carry, a point which is discussed in more detail in a later section. As a result, if gas cooling is adopted, the only practicable arrangement is one in which the strips are divided into two stacks separated by a centre channel through which the hydrogen flows from one end of the stator to the other. Even with this arrangement, some difficulty will arise with the largest machines in providing sufficient pressure head to obtain the necessary mass flow and at the same time allow sufficient space for the copper.

On the other hand, the absence of mechanical stress in the copper, or of static head developed in the coolant such as would arise in the rotor due to its rotation, introduces the possibility of using a liquid in place of gas to extract the heat from the stator windings. Since the heat capacity of a liquid is many times greater than that of hydrogen, the area required

for cooling ducts within the main slot insulation is smaller and the advantage to be gained by direct cooling becomes more marked. The pressure required to circulate the necessary mass of liquid through a conductor is so low that a number of conductors may be connected in series, the insulation requirements are eased and there is no difficulty in cooling effectually units of the largest size.

In practice there are two possible liquid coolants, water and transformer oil, and after a very complete investigation the former has been selected as the more suitable for the following reasons. Water has a somewhat higher specific gravity and about twice the specific heat; its thermal capacity is therefore much greater and an appreciably smaller mass flow is required to absorb a given loss. Furthermore, it has a much lower viscosity and this, combined with the smaller volume, permits the overall length of coolant circuit to be increased or the cross-sectional area to be reduced on the basis of equal pressure drop for the two liquids. Transformer oil has high dielectric strength so that only a relatively short distance is required to provide a high resistance path to isolate the windings from the earthed supply and discharge oil pipes inside the casing; but distilled water is not a good conductor and in the arrangement to be described there is no difficulty in obtaining an ample resistance in the water pipes to the windings. The use of water eliminates the possibility of fire hazard such as would be present with transformer oil.

WATER CIRCUIT.

The ideal direct cooling arrangement, from the point of view of minimum disturbance to the insulation, would be one in which the coolant path was totally contained within the normal insulation of the windings with the supply and discharge points at earth potential. Thus, the circulation would be from the neutral point, through half the conductors of one phase to the line terminal and back through the remainder of the phase conductors to the neutral point. The scheme has some thermal disadvantages but, more important, the pressure drop through such a coolant path would be high and, since it is desirable to limit the maximum water pressure to a value below that of the hydrogen in the casing, the number of conductors in series must be reduced with additional tapping points to the windings to provide lower resistance paths for water flow.

The arrangement finally adopted and illustrated diagrammatically[2] in fig. 1 provides a neat and simple solution to the problem with the advantage that all pipework within the stator casing is metallic with brazed joints. In the diagram the stator windings are represented by the thick lines, each phase being divided electrically into two parallel windings; this is essential in units of the size under consideration. The water flow is into both ends of each phase winding with discharges at the centre points of each half phase, thus providing 12 coolant circuits in parallel through the stator.

The terminal bushings have hollow stems through which the water passes into the casing and the arrangement serves a double purpose since the efficient cooling of the bushing by cold water greatly increases the current-carrying capacity and eliminates the possibility of any expansion stress. Three small bushings are also required for the warm water discharging from the windings, the connection between them and the mid points of each phase being made with metal pipes insulated and supported in a similar manner to the electrical leads. The points at which the warm water will leave the windings are indicated in fig. 2, which shows a typical stator winding of a 60 MW machine. In order to break down the voltage between the bushings and the earthed water circulating pump and heat exchanger, resistance columns are provided at any

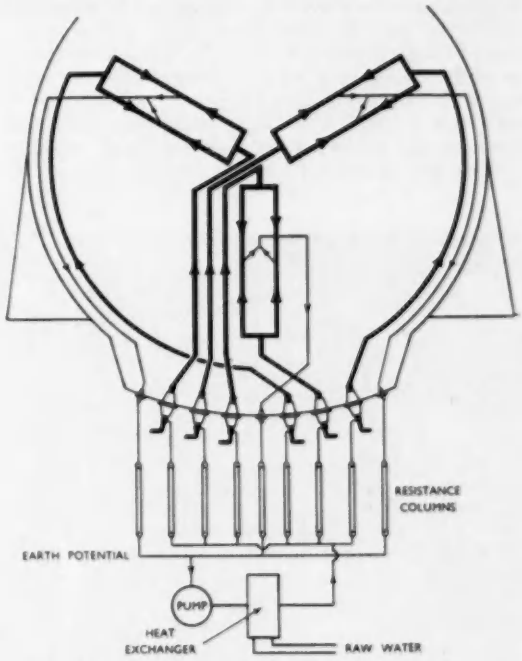

Fig. 1.—Diagrammatic arrangement of the water-cooling circuit for the stator winding.

convenient position in the foundation block. These are very simple and consist of straight tubes of insulation material having a length and diameter selected to contain a column of water of the required electrical resistance.

STATOR CONDUCTORS.

A section through a G.E.C. water cooled stator conductor[2] is shown in fig. 3. It consists of a number of thin walled but robust copper tubes spaced symmetrically within the conductor, each tube being associated with two solid copper strips placed above and below it with only light insulation interposed. The

water circulates through all tubes in parallel, the quantity through each being designed to absorb the loss both in the tube itself and in the associated strips. Since the heat is transferred from the latter to the tube over a wide area the temperature gradient across the insulation is negligible and all the copper in the conductor at any section is at substantially the same temperature.

One of the chief advantages of the arrangement compared with one using tubes alone is the greater freedom to select the most suitable proportions for the various components from the point of view of losses, hydraulic efficiency and ease of handling. Thus, if a few tubes are arranged to provide the same total duct section the depth of each tube and the wall thickness become too great having regard to eddy current losses, while with a larger number of tubes of more suitable wall thickness the water duct cross-section becomes long and narrow and the pressure drop across a given length is appreciably higher. For example, if the sub-conductor of fig. 4 (a) were redesigned without strips and with, say, 5 tubes per stack, each would become nearly square with only a small hole in the centre, fig. 4(b), and although the somewhat higher space factor obtained due to less interstrip insulation would reduce the ohmic loss, this would be more than offset by higher eddy current losses and the nett effect would be an increase in total loss and temperature rise. With twice this number of tubes, fig. 4(c), the stray loss is lower, but since the cross-section of the bore will be halved and the wetted perimeter is reduced only slightly, the equivalent hydraulic mean diameter is also approximately halved. The pressure drop therefore will be nearly doubled and an increase in the number of tapping points to the windings is necessary. The combination of tubes and strips, fig. 4(a), allows the greater part of the current to be carried by the most effective conductors, viz. insulated thin laminations, and the water to flow in a few channels of reasonably good shape to give low pressure drop, the walls of the tubes also being used to carry current.

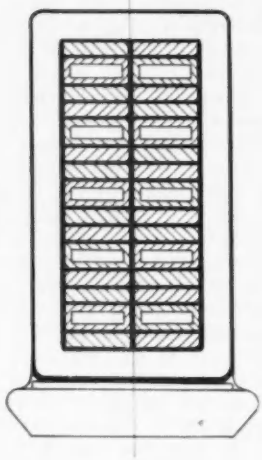

Fig. 3.—Section through a water-cooled stator conductor using tubes and solid copper strips.

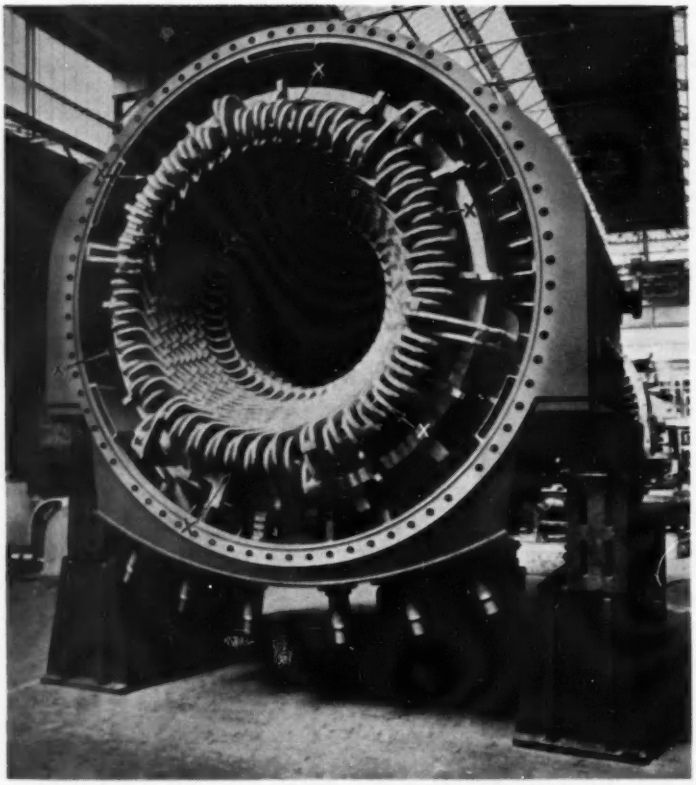

Fig. 2.—Typical stator winding. The six points marked "X" indicate the positions at which the water leaves the winding.

ARRANGEMENT OF STATOR WINDINGS.

It is well known that the stator conductors of all but the smallest alternators are subdivided to reduce the eddy current losses, the usual method being to use a number of horizontal laminations which are individually insulated and transposed. This transposition may be arranged in two ways. First, each strip or group of strips may be cyclically transferred from one position in the slot to an adjacent position when making the joints between conductors in the stator overhang, the interstrip

insulation being continuous throughout the winding. Secondly, the laminations may be divided into two across the slot width, the strips being "twisted" or transferred from one stack to the other so that each strip occupies all positions in the depth of the conductor within a single slot, i.e. a "Roebel" bar is formed. The former method has always been used by the Company; it has the advantages of very simple interstrip insulation, uniform depth of copper and the highest space factor in the slot, with better equalisation of induced stray voltages in the stator overhang. The same arrangement with minor modifications will be used for a direct cooled winding.

In the past it has been the practice to arrange for the number of laminations per conductor to be equal to, or a multiple of, the number of stator coils in series per circuit, thus giving one transposition cycle in the winding. It is also possible to obtain 2 cycles either by halving the number of laminations or by doubling the number transferred per joint. With a conventionally cooled stator conductor this alteration could either decrease or increase the total eddy current loss depending on the original relative values of the several components of loss (local and circulating current), but it is very suitable for the arrangement of the water-cooled conductor shown in fig. 3 since it results in the most favourable proportions for both the strips and the tubes. The subdivision of the strips in this conductor in a vertical direction is standard G.E.C. practice when the total copper width exceeds a specified figure.

The transposition at the joints may be made using "jumpers" to transfer the required number of strips from the top to the bottom of the stack of laminations when making the brazed joints to the next coil, and the axial standout of the windings from the core may be reduced by using a "split" coil end, i.e. arranging half the strips to be jointed in one radial plane and the remainder in another displaced by one half slot pitch. Using a split coil end with a suitable number of strips in the two groups of laminations results in correct transposition without the necessity for jumpers and at both ends of the stator the strips follow round top to bottom in an orderly sequence.[3] Such an arrangement is, of course, very desirable, particularly with a direct cooled winding, to facilitate the jointing of the tubes. Fig. 5 illustrates the principle and it will be seen that the position of the black strip has altered in adjacent slots without any irregularity in the joints.

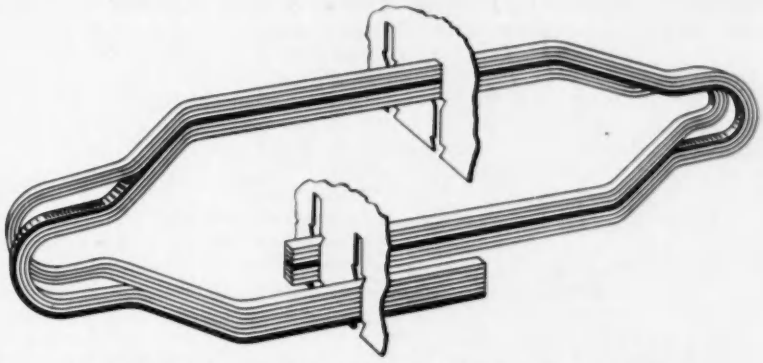

Fig. 5.—Method of transposition of the laminations forming the stator conductor.

INSULATION.

From the previous remarks it will be clear that the insulation of the windings is exactly the same as that used successfully for many years. At only six points where the warm water discharge pipes leave the windings is the appearance different from that of a conventionally cooled stator but here again a standard

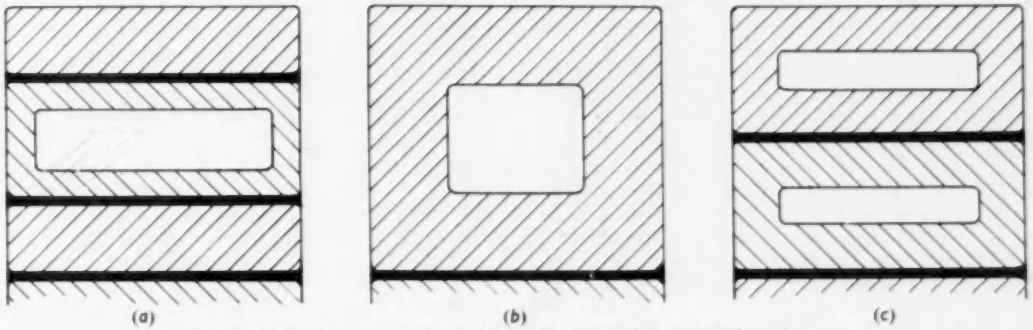

Fig. 4.—Section through different forms of water-cooled stator sub-conductors.
(a) Design adopted by G.E.C.; (b) Single tube without solid copper strips; (c) Two tubes without solid copper strips.

insulation technique is employed, the taping being continuous down to the bushings as on the main electrical leads.

STATOR CORE VENTILATION.

The design of the stator conductors of a conventionally cooled alternator must take into account not only the copper section but also the height and width of the slot since it is essential to maintain sufficient surface area of insulation to limit the temperature gradient from copper to iron. With direct cooling, only the area of the conductors need be considered ; the restriction on slot width is removed and in order to take the fullest advantage of this fact other modifications to the stator ventilation have been incorporated in the Company's design for large units.[4]

Referring to the diagrammatic arrangement of fig. 6, it will be seen that in place of the usual radial ventilation of the stator core, an axial system is used, the gas being drawn through holes in the core plates by the high head impeller also used to ventilate the rotor. The high gas velocity and the large area of contact with each lamination results in most efficient heat transfer from the iron. Since this gas has only to absorb the iron loss, the volume is smaller than that required for a conventional machine in which it also cools the windings.

The elimination of most of the radial ducts increases the number of laminations which can be stacked in a given axial length and for the same flux density in the teeth the slot width may be increased by 15-20 per cent. With constant insulation thickness the wider slot in turn results in a greater percentage increase in copper width, the depth of conductor is reduced and both the height of slot and the outside diameter of the coreplate can be appreciably smaller. After allowing for the greater effective length of iron, the smaller diameters will reduce the nett weight of coreplate and there will be a further saving on the stator casing. In practice, the permissible slot width is determined from considerations of total iron loss rather than equal tooth flux density ; with the smaller volume of core this density may be increased, so permitting a still wider slot with correspondingly greater saving in overall diameter and weight.

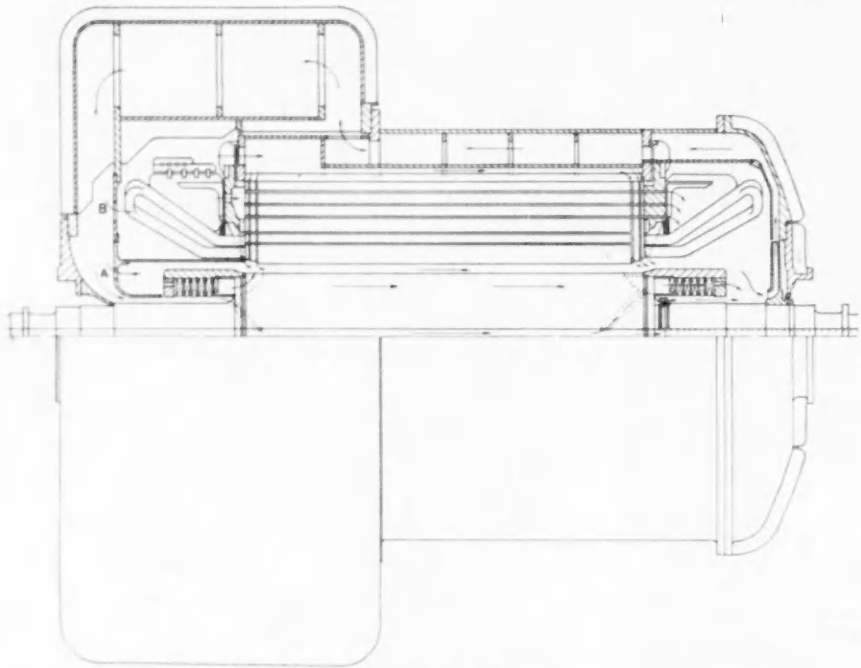

Fig. 6.—Ventilating system for hydrogen cooling of the rotor and stator core.

As was mentioned in the previous article, the reduction in frame size made possible by the direct cooled rotor must result in increased specific loading on the stator and it is necessary to ensure that this does not lead to localised high temperatures, particularly at the ends of the stator. Exhaustive tests made at the Witton Engineering Works and on site on alternators fitted both with magnetic and non-magnetic rotor winding support rings have demonstrated that on a G.E.C. alternator of modern design the temperature rises are moderate and have also provided data to confirm the predicted satisfactory temperature levels of the alternators at present under construction.

With a view to still further increases in output, the design illustrated in fig. 6 embodies a separate ventilation circuit for the core end packets and clamping plates. Briefly, cold gas is allowed to pass to the gap from the back of the core through one or two radial ducts at both ends of the stator and also through passages provided in suitable positions in the core clamping plates. A number of modifications have also been made in the construction of the stator ends to reduce still further the stray losses.

The cooling gas is circulated by the high head impeller mounted on the outboard end of the rotor shaft, the axial flow fan normally used for stator ventilation being eliminated. The pressure differential across the machine—as distinct from the return path through the gas coolers and connecting ducts—is determined by the drop through the rotor conductors. In general this pressure differential will be more than adequate for the stator core and in particular for the relatively small volume of gas required to pass along the gap. It is therefore necessary to reduce the pressure available and the very simple arrangement shown in fig. 6 provides not only for the separation of the circuits, but also for facilities to adjust the gas distribution should this be found desirable on test. The rotor cooling gas passes without restriction into the space under the windings at the inboard end ; the gas for the gap is provided mainly by a flow through a coarsely-adjusted clearance between the baffle ring and rotor end plate and may be augmented through the orifice plates at *A*. The cooling of the stator core as a whole is controlled by the apertures at *B*, while the relative volume passing to ventilate the stator ends is pre-set by plates at the entrance to the transfer ducts at the back of the core. By these means an efficient and very flexible ventilation arrangement is obtained.

HEAVY CURRENT BUSHINGS AND CONNECTORS.

For various reasons the increase in unit output has not been accompanied by a corresponding increase in the machine voltage and therefore the stator current will be appreciably higher ; for example, it is of the order of 10,000 amp for a 300 MW alternator. A naturally cooled terminal bushing of this size would probably be impracticable and even at lower currents direct gas cooling has been used. As previously mentioned, the water cooled bushings of fig. 1 have greatly increased current carrying capacity and there will be no difficulty in dealing with even greater ratings.

The excitation current for these large units is also greater than present common usage due to the increased power requirements, and the desire to limit the d.c. voltage to a figure of the order of 500/600 volts. As far as the conductors are concerned, the larger current causes no difficulty but it is an advantage to restrict the diameter of the radial connectors between the windings and the slipring leads to limit the effect on the shaft stiffness. Here again, advantage may be taken of direct cooling to reduce the size, cold gas being drawn from the inboard end of the rotor, through the trepanned bore and out through the connectors.[5] The ventilation of the bore has the incidental advantage of eliminating the possibility of condensation which has on occasion caused some difficulty in conventionally cooled machines.

PROTOTYPE ALTERNATOR.

The design of the conductors for a direct cooled stator winding is in many ways more exact than that of the conventional machine since the heat paths are more clearly defined and the temperature rise may be predetermined with accuracy. The arrangement of water circuits just described is one in which only metal pipework and well-established jointing and insulating techniques are used within the stator casing. Satisfactory operation can, therefore, be predicted with every confidence and the reliability of the windings will be enhanced by the relatively low maximum temperature of the copper. At the same time, before applying the principle to units in excess of, say, 200 MW, when the benefit starts to become apparent, it is desirable to obtain experience on a smaller machine and with the co-operation of Mr. A. R. Cooper, Controller of the North-Western Division of the Central Electricity Authority, it has been agreed that this feature should be incorporated on one of the 60 MW direct rotor cooled alternators to be installed in the Bold " B " Power Sation. Since the object is to determine the most satisfactory layout of the hydraulic system, to establish manufacturing techniques and to confirm the performance and reliability of the water cooling circuit, it is not proposed to embody any of the other features which have been described, and apart from the conductors, the stator cooling system will remain unaltered.

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1. *G.E.C. Journal*, Vol. 22, pp. 155-160, July, 1955.
2. British Patent Application No. 20423/56.
3. British Patent Application No. 16326/54.
4. British Patent Application No. 2811/57.
5. British Patent Application No. 2810/57.

Conversion to A.C. Drives at a Yorkshire Woollen Mill

By C. R. BARON,
Witton Engineering Works.

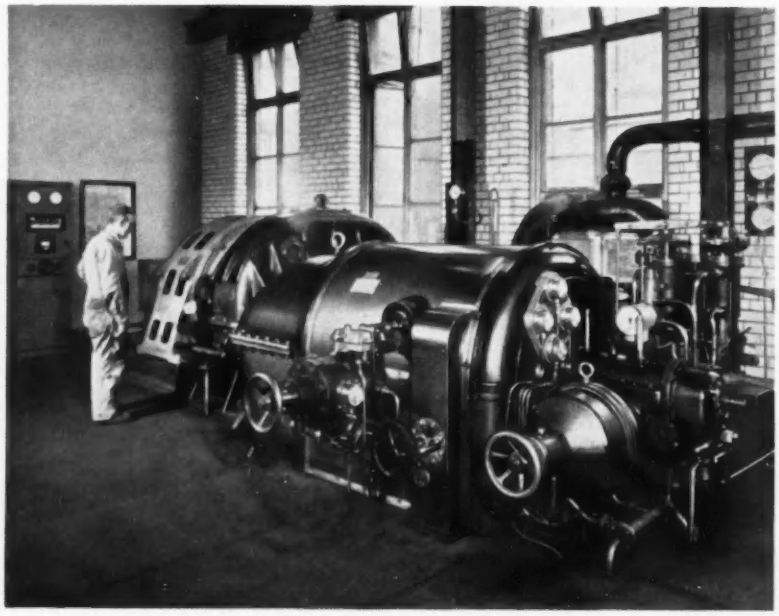

Fig. 1.—1,250 kW, 415 volt turbo-alternator.

CHEAPSIDE MILL is one of three, all engaged in woollen manufacture, owned by J. T. & J. Taylor Ltd., Batley, Yorkshire. This firm was founded in 1845 and has ever since been one of the best-known woollen manufacturers in the county. In 1892, under the leadership of the late Theodore Taylor, it became one of the first profit-sharing concerns in Britain.

From 1906 onwards, the Cheapside Mill was supplied with power by a Hick Hargreaves engine and two smaller steam engines, one of which drove a d.c. generator. By 1936 it was appreciated that, due to the considerable process-steam demand, a pass-out turbine would provide the most economical source of power. Accordingly, the Hick Hargreaves engine was taken out and a G.E.C. turbine was installed to drive through gears on to the existing engine pulley, the belt, clutch and gearing drives to the old mill portion being still utilised. A 550 kW direct-coupled d.c. generator was also driven by the turbine, providing power at 230 volts for machinery in all buildings except the old mill.

REASONS FOR CONVERSION.

Certain aspects of the installation in 1936, which at that time were considered the best practice, have since proved uneconomic due to changing circumstances. Some of the line-shafts retained for driving the old mill were over fifty years old and involved high friction losses and expensive maintenance, all the bearings being either grease- or oil-bottle lubricated. A total of eight clutches, many of which had become out of alignment, were expensive to maintain, and some three miles in all of belts and ropes required frequent

adjustment and, at intervals, expensive replacement.

The maintenance of the d.c. system also proved expensive. While d.c. motors may be useful where speed variation is essential, the cost of replacing these machines when worn out and the maintenance costs of replacing brushes, skimming commutators, etc., causes them to compare unfavourably in these respects with the more robust squirrel cage motor. In addition, extensions to the d.c. system were expensive on account of the high cost of cabling. A further disadvantage of the d.c. supply was becoming apparent with the need, in many of the processes, to use fluorescent lighting. Yet another problem arising from the d.c. system was the fact that new machines are usually offered with individual a.c. drives, and the need for specifying d.c. motors, which were non-standard, made deliveries difficult besides involving higher capital cost. Finally—the most important factor of all in a textile installation, as in most other factories—was the necessity of avoiding loss of production due to failure of the power supply to the machines. From this point of view an a.c. supply in conjunction with squirrel cage induction motors compares very favourably with a d.c. system. All these factors combined in leading to the decision to convert the mill to a.c.

The generating plant, switchgear and cabling necessary for the conversion, together with a large number of motors and their associated control gear, were supplied by the G.E.C.

POWER SUPPLY.

In designing the power supply system for a textile mill, it is frequently necessary to consider factors other than the purely electrical loading. In the woollen industry, it is usual for almost all the processes involved in the preparation, weaving and finishing of cloth to be carried out on a single site. Many of these processes use a considerable quantity of steam and, if the total demand is sufficiently great, the installation of turbine-driven generating plant can be justified on the grounds that it constitutes an economical means of supplying both electrical energy and process-steam which can be bled from the turbine.

These conditions obtained at the Cheapside Mill and it was therefore decided to retain the pass-out turbine, but to replace the d.c. generator and rope pulley by a 1,250 kW, 3-phase alternator (fig. 1). The turbine, which operates at steam conditions of 160 p.s.i. and 550/660 deg. F., is rated at 1,650 h.p., 6,000 r.p.m., and is coupled to the alternator through

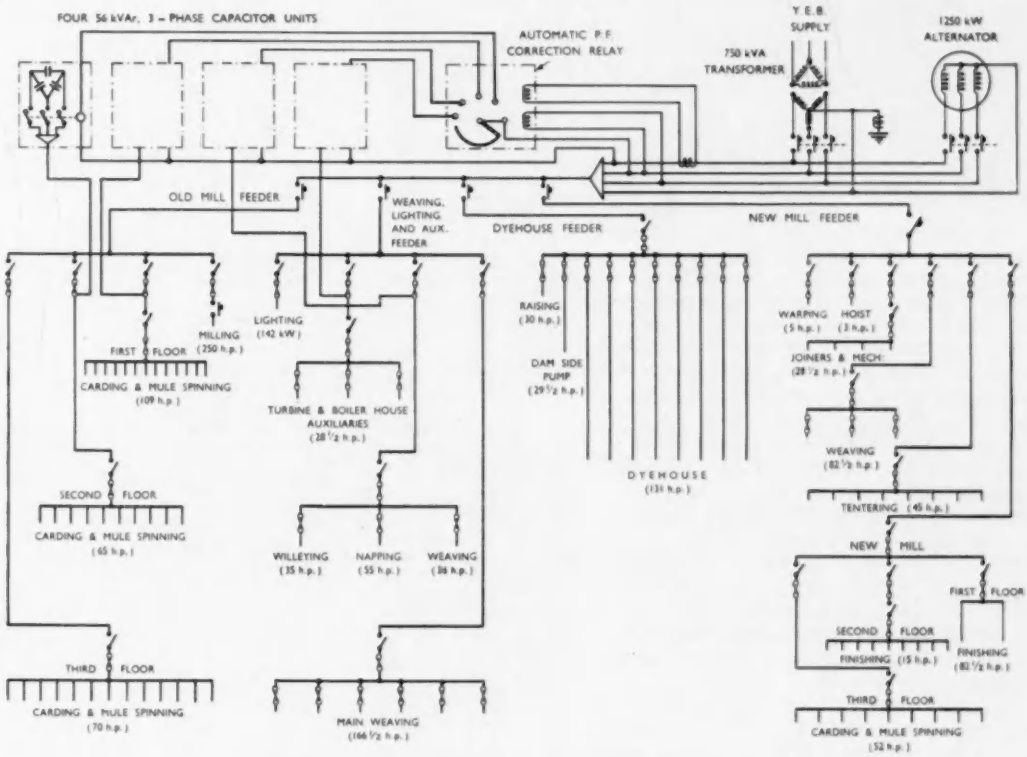

Fig. 2.—Simplified diagram of electrical distribution system.

Fig. 3.—Air-break main switchboard in the power house.

gearing which reduces the speed to 500 r.p.m. The alternator generates at 415 volts and a power factor of 0·8, and is fitted with a direct-coupled exciter. The total steam demand for process supplies and for heating when the mill is in full operation is in the region of 25,000 lb. per hour. This steam is bled from the turbine at 30 lb. per sq. in.

A power supply from the Yorkshire Electricity Board was also installed for regular night and overtime use when the load is too low to justify running the alternator, and the process-steam demand is also low. This supply is also sufficient to keep basic departments running during periods of maintenance on the turbo-generator plant. Permission was granted by the Area Board to synchronise the alternator momentarily with the public supply, when starting up or shutting down the works set, in order to keep continuous processes in operation. A simplified diagram of the power supply system for the whole mill is shown in fig. 2.

MAIN SWITCHGEAR.

The main switchboard (fig. 3) which is installed in the power house, is of the G.E.C. standard cubicle type with air-break gear. This type of switchgear is rapidly replacing the older industrial oil-immersed switchgear for medium-voltage installations. The absence of oil reduces the fire-risk considerably, a particularly important factor in woollen mills. In addition, the air-break equipments are proving very much easier and quicker to maintain and keep clean; furthermore, they are compact and of pleasing appearance.

In this particular case, the switchboard comprises control gear for alternator excitation; two air circuit breakers, rated at 2,000 amp and 1,200 amp respectively, for the incoming supplies from the alternator and from the public supply; four further air circuit breakers, each rated at 800 amp, for main feeder control; and eight 400 amp fused switches for distribution circuits adjacent to the power house. The circuit breakers are arranged for manual operation, although solenoid-operated equipment of this type can be supplied when required.

The saving of space compared with equivalent industrial oil-immersed gear is seen in the case of the 800 amp circuit breaker units, which are arranged in two-tier formation. The use of special alloys has kept the weight of the breakers low enough for units in either tier to be easily removed from the cubicles for inspection and maintenance. The cables enter the switchboard from beneath the floor, and full-width rear doors on the cubicles permit easy access to the interior of the board for maintenance and for cabling.

DISTRIBUTION SWITCHGEAR.

The ironclad distribution switchgear, located in the various sections of the mill, was built up by the mill

Fig. 4.—Ironclad main distribution board for the new mill section installed in the warping department.

staff from the standard range of components developed by the G.E.C. This range comprises a wide variety of ironclad air circuit breakers, fused switches and switch-fuses, together with cable boxes, busbar chambers and supporting pedestals, all designed so that the greatest possible number of combinations of different units can be assembled to meet individual requirements.

The main distribution board for the new mill section, which is illustrated in fig. 4, is typical of the equipment employed throughout the installation. It embodies a 400 amp air circuit breaker which controls the incoming supply from the main switchboard, while the outgoing feeder units comprise two 200 amp fused switches and four 60 amp switch-fuses. All these units are connected through two standard pressed steel busbar chambers coupled together, and the whole is mounted on sheet steel pedestals fitted with back support brackets. The outgoing feeders from this switchboard supply the whole of the new mill section of the installation, further ironclad switchboards and fuse-boards being provided, where necessary, for the various sub-distribution circuits in the individual departments.

Fig. 5.—A Fearnought machine with motor drive and direct-to-line starter.

CABLES.

The power supply cables for the modernisation scheme were manufactured by Pirelli-General Cable Works Ltd., who were also responsible for the installation of the main feeders. As a general principle, it was decided to avoid the use of very large cables by employing, where necessary, smaller-diameter runs in parallel. This arrangement permitted a much neater installation to be obtained, using smaller bends, and in many cases reduced the overall first cost. A further advantage was that, in case of a cable fault, a portion of the load could still be carried on the unaffected cables.

All the main cables are paper-insulated, lead-covered, single-wire-armoured and served and, in the majority of cases, are 3-core. On vertical runs, racks and wood clamps are used and on all horizontal runs the cables are supported in hangers. As most of the cables are installed in fairly dry surroundings, cable sealing boxes were not considered necessary, the cable tails being sealed against moisture by means of high-voltage tape.

For supplying isolated motors, V.R. cables were run in enamelled conduit, while for machines more closely grouped V.R. cables in trunking were used. In the weaving shed, where rows of up to twenty motors were fed from each length of trunking, individual fused tap-off units were employed. For the dyehouse, where the wiring is subject to attack from chemical fumes and steam, P.V.C. cables were used in galvanised conduit, the conduit being painted outside with synthetic anti-rust paint. Several systems of tapping-off from the P.V.C. bus cables in the conduit were considered and, finally, the engineering staff of the mill designed and made a special moisture-proof container to house the standard tap-off unit and fuses supplying the individual dye-vat motors. This arrangement is standing up extremely well to the onerous conditions.

The connections between motors and starters were considered to be the sections most liable to deterioration, and the installation was designed so that these runs are easily renewable.

One of the chief difficulties in designing a distribution system is the assumption of the load factor to be applied to the total horse-power of motors connected, in order to obtain the continuous rating of the cables. The following figures, which have been previously used on similar installations, have been found to give a reasonable margin of safety on both main and sub-distribution cables.

	Load Factor
For small groups of motors	0·9
For main cables to a department	0·8
Overall load factor for the complete mill	0·7

MOTORS AND STARTERS.

The first problem faced in all departments was whether to use individual or group drives. While individual drives are universal in the case of new textile

machines, there are cases in conversion schemes where the group drive is so much cheaper, taking into consideration the fact that the final belt-drives are existing, that it may be worth tolerating the attendant disadvantages. It is usually found that, from the point of view of efficiency, the two methods of driving are comparable, as the friction losses of the belts and shafting are off-set by the higher efficiency of the group-drive motor as compared with the smaller individual-drive motors. In general, it may be said that where several motors are used, all running together or all stopped, as would be the case in a set of drawing machinery, the group drive is often the most economical choice. In most other cases, for instance for looms, spinning-frames, etc., where it is an advantage to be able to shut down individual machines, the individual motor drive shows advantages. There is a considerable improvement in working conditions in the rooms where the machines are converted to individual drive ; reduction in noise is considerable, the danger from belting is removed and a much more satisfactory lighting installation can be provided due to the absence of overhead belts, line-shafts and pulleys.

It was found that, by adopting individual drives in all except the milling department, the largest motor required, with this one exception, was rated at 35 h.p., a factor which reduces to a minimum the potential cost of replacements in case of individual machine failures. Furthermore, the introduction of the a.c. supply system enabled full use to be made of the squirrel cage motor, which offers the advantages of robustness and reliability together with the ability to use comparatively simple and inexpensive control equipment.

The conditions in most sections of the mill, as in most centres of textile manufacture, are such that a great deal of dust and fluff is present in the atmosphere. This necessitates the use of a type of motor enclosure which is completely dust-proof. Many of the motors installed are of the G.E.C. totally enclosed fan-cooled design, in which the cooling air from a fan mounted externally to the frame of the machine is directed over the finned surface of the shell by means of a cowl. All these motors are manufactured to the standardised dimensions specified in British Standard 2083, a feature which allows for complete interchangeability of machines of the same rating and considerably reduces replacement problems. A typical motor of this design is shown in fig. 5, which illustrates a Fearnought machine in the preparation section of the mill.

Direct-to-line starters are provided for all motors up to and including 15 h.p., while larger machines are equipped for star-delta starting.

The conversion of the carding engines, one of which is shown in fig. 6, was one of the more difficult problems. These carding sets comprise two portions, each of which was to be driven by a separate motor. The wool sliver passes from one section to the other and must not be either stretched or allowed to pile up due to differences in speed between the two sections of the set. The starting inertia is very high and the speed of the driven wheel is of the order of 65 to 70 r.p.m.

Conversion of the carding engines was carried out by using individual 5 h.p. squirrel cage motors driving through flat plastic leather belts, the use of this belting allowing a single-reduction drive from motors running at 710 r.p.m., using what has hitherto been considered the very high ratio of 11 : 1. This type of drive makes a much neater and less expensive installation than when a gear unit is incorporated. Very expensive speed-matching equipments are sometimes installed for this class of drive, but it was decided that, provided squirrel cage motors with the same percentage slip were employed, the speeds should keep sufficiently synchronised, and this has, in fact, proved to be the case.

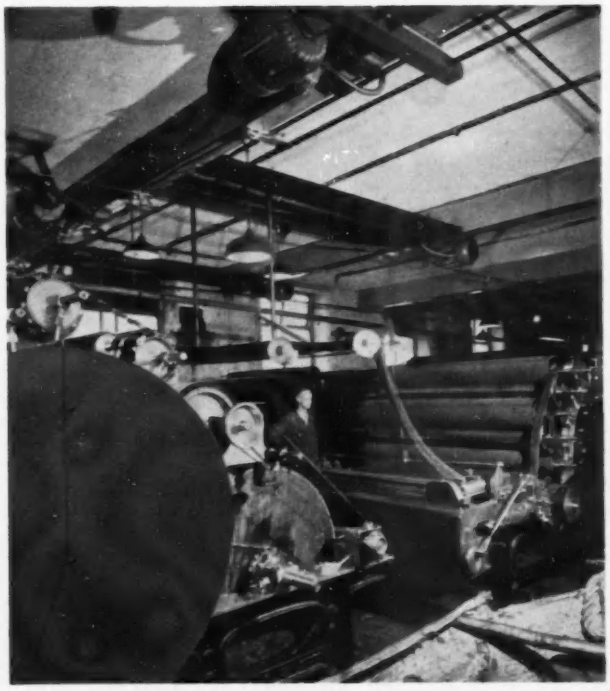

Fig. 6.—One of the carding sections ; the motors are driving carding machines on the floor above.

The high inertia of the carding engine presents certain difficulties in the matter of starting. In this installation the problem was solved by providing the starters with saturable-core overcurrent relays. These devices, the design of which has been patented by the G.E.C., will carry the heavy starting currents of the motors, thus preventing tripping while the machine is accelerating up to speed, but afford full overload

protection during normal running. In the carding sections, and also in the case of the spinning mules (fig. 7), the starters are arranged in groups, remote pushbutton controls being mounted in convenient positions on the machines themselves.

In general, the machines in the finishing department are equipped with standard totally enclosed fan-cooled motors provided with direct-to-line starters. A typical example is shown in fig. 8, which illustrates a Bailey blowing machine driven by a 5 h.p., 720 r.p.m. motor which amply demonstrates the compactness and accessibility of the electric drive. One of the few departures from a straightforward drive is found in the case of the moser raising gig, shown in fig. 9, where difficulties due to high inertia have been overcome by fitting a centrifugal clutch on the motor shaft in order to relieve the starting load.

In one or two cases it was considered desirable to retain the original d.c. driving motors, notably for the centrifuges in the dyehouse, where the cost of conversion would have been excessive, and also for certain hoists and cranes. To provide the supplies for these machines, selenium rectifiers, manufactured by Salford Electrical Instruments Ltd., were installed.

Fig. 8.—Bailey blowing machine in the finishing department.

POWER FACTOR CORRECTION.

In cases where motors or other equipment taking magnetising current from the public supply are installed, the tariff almost always makes it essential to improve the power factor to a figure between 0·95 and 0·975.

The two commonest methods of improving the power factor are either to provide each motor with its

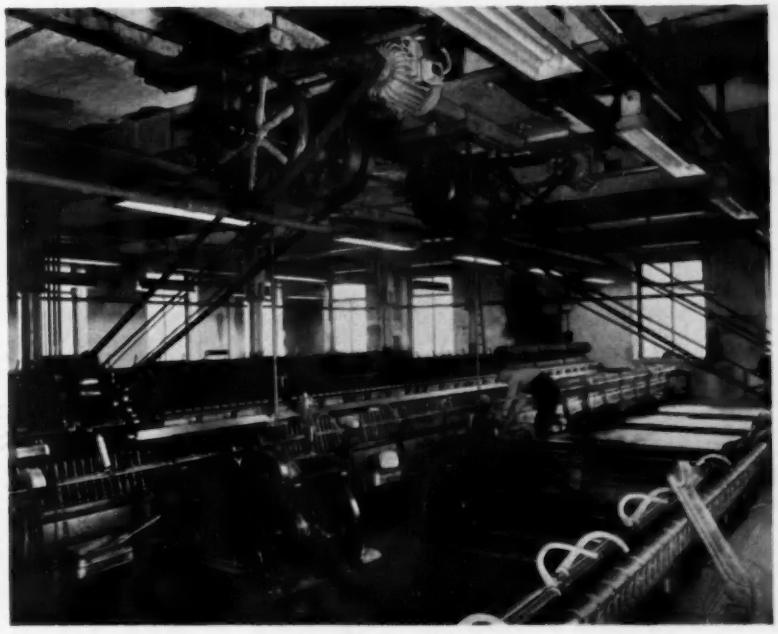

Fig. 7.—Spinning mule drives.

Fig. 9.—Moser raising gig, showing motor and housing for the centrifugal clutch.

own capacitor or, alternatively, to install a number of larger capacitors controlled by a relay operating from the main incoming supply and arranged so that the capacitor units are switched in or out with varying total load. Advantages of individual correction are, first, that the power factor is maintained at the desired value, as the capacitors for each motor are solidly connected across the terminals and are switched in and out with the machine, and, secondly, that by reducing the current at the motor itself, the size of the cables is kept to a minimum. The cost, however, of a large number of small units together with the cost of wiring up, is naturally greater than in the case of large units, and, in the present instance, the automatic system, using large capacitors, was adopted.

The equipment supplied for Cheapside Mill comprises four three-phase capacitors (fig. 10), each rated at 56 kVAr, which are mounted in the basement beneath the power house. The connections are shown in fig. 2. Each of the capacitors, which were manufactured by Standard Telephones and Cables Ltd., is fitted with its own contactor unit. These contactors can be operated manually, but are normally under the control of a Chamberlain & Hookham automatic power-factor correction relay mounted on one end of the main switchboard. This relay includes an element, of the induction watt-hour meter type, which continuously measures the reactive component of the power drawn from the supply, and, on this basis, controls the operation of a small reversible motor driving a stepper switch. Movement of this switch makes or breaks, according to the direction of motion, the operating circuits for the four contactor units, and the setting of the relay is such that, at any instant, the total capacitance in circuit is sufficient to maintain the overall power factor at a satisfactory level, whatever the power demand may be.

Results in service have shown that the power factor is kept to a figure of approximately 0·965 lagging.

It is usually found that the installation of power-factor correction equipment, by its saving in power costs, pays for the capital cost of the capacitors in approximately two years.

LIGHTING.

Considerable use is made of fluorescent lighting throughout the mill and, now that an adequate a.c. supply is available, further extensions can readily be made. During the conversion itself, the opportunity was taken to equip several departments with this type of illumination, the weaving sheds being one example where the installation was designed to give a nominal light intensity of 25 lumens per square foot after 100 hours' lamp life.

The lighting supplies to the whole mill are carried by one feeder from the main switchboard. The separate control which is thus available possesses the advantage that, in case of fire, the mill lighting can be left on while all other power supplies are disconnected.

CONCLUSION.

The programme which was worked out for the conversion to a.c. operation was designed to allow this to be carried out without any loss of production, and this object was achieved.

Fig. 10.—The four 56 kVAr power-factor correction capacitor units in the power house basement.

During the first six months after beginning operations, the shafting and belt-drives in the old mill were removed and the machines were converted, one by one, to individual drive, the supply being obtained from the Yorkshire Electricity Board.

During the first summer holiday period, when the generating set could be shut down, the large flywheel was broken up and removed, a concrete floor was put in the now vacant belt-race and the main switchboard was erected and connected up to control the supply from the Y.E.B. to the portions already electrified. In the holiday period of the next year, the d.c. generator was removed and the alternator was coupled up and commissioned.

The results of the changeover may be summarised as follows :

(1) A large reduction in the load has been experienced, due to the elimination of friction losses from shafting, belt-drives, etc. ; the higher efficiency of a.c. drives compared with d.c. ; and the ability to shut down completely any machine which is not actually in production at any one time.

(2) Working conditions have improved considerably due to reductions in noise, better lighting resulting from the removal of overhead belts and shafting, and greater safety, again brought about by the elimination of belt-drives.

(3) The amount of maintenance work has been considerably reduced.

(4) In the case of carding engines and spinning mules, the smoother drives from the a.c. motors are giving an improved product.

(5) It has now been possible to install considerable quantities of fluorescent lighting, which is proving very popular with the operators.

(6) The ability to operate the factory from the public supply at periods when the load is too low to justify running the turbine, has shown considerable savings in power costs, while, at heavy load periods, extremely economical power generation, using the pass-out turbine, is still realised.

ACKNOWLEDGMENTS.

Acknowledgments are due to J. T. & J. Taylor Limited, for permission to publish this article and for assistance in compiling the information and in obtaining photographs.

LIFTING MAGNETS FOR INDIA

This important consignment of lifting magnets, is being loaded at the Witton Engineering Works for despatch to The Indian Iron and Steel Co. Ltd. at Durgapur. These magnets are some of the largest built. Each is 65 inches in diameter, weighs 6½ tons, uses 30 kilowatts of power and can lift 30 tons of solid steel ingots or slabs.

Over half the Company's output of lifting magnets goes abroad, the principal markets being Canada and India.

TECHNICAL LITERATURE

A digest of recent articles and papers by members of the G.E.C. and its associated companies

MEASURING TURBINE BLADE VIBRATIONS.*

By G. A. Luck (Fraser & Chalmers Engineering Works) and R. C. Kell (Research Laboratories).

Engineering, *Vol.* 182, *pp.* 271-273, *August* 31, 1956.

The authors describe the development of barium titanate transducers both for detecting and exciting vibrations in turbine blades, and give an account of experiments on stationary and rotating wheels carried out in the Vibration Laboratory of the Fraser & Chalmers Engineering Works. Advantages and limitations of this type of piezo-electric device are discussed.

SEMICONDUCTORS: THE PRESENT AND FUTURE POSITION.*

By N. L. Harris (Research Laboratories).

British Communications and Electronics, *Vol.* 3, *pp.* 466-471, *September*, 1956, and *pp.* 526-530, *October*, 1956.

Part 1 of this article gives an account of the relationship between semiconductors currently available and the state of their development, technology and applications. In Part 2 possible future trends are discussed in the development and application of semiconductor devices, with their limitations and economics of manufacture. Both transistors and other crystal devices are dealt with.

BAND-PASS CHARACTERISTICS OF LOW ASYMMETRY.

By B. Easter (Research Laboratories).

Electronic Engineering, *Vol.* 28, *pp.* 156-158, *April*, 1956.

The nature of the asymmetry of conventional band-pass filter characteristics is considered using the concept of the complex frequency plane. An empirical rule is then stated whereby characteristics of much reduced asymmetry may be designed. The discussion is illustrated by two band-pass characteristics of similar form, one derived by conventional methods and one by the procedure described.

METHODS OF GROWING CRYSTALS.

By M. A. Short (Research Laboratories).

The Industrial Chemist, *Vol.* 33, *pp.* 3-8, *January*, 1957.

The author provides a comprehensive review of methods of growing crystals. The methods are considered under four distinct headings : from the solid state, from the melt, from the vapour, and from solution.

THE LIGHTING ENGINEER'S APPROACH TO THE LIGHTING OF NEW CHURCHES.

By M. W. Peirce (Head Office, I.E. Department) and J. M. Waldram (Research Laboratories).

Light and Lighting, *Vol.* 49, *pp.* 151-155, *June*, 1956.

The diversity of style, layout, symbolism and materials in modern churches makes it impossible to lay down many rules for lighting them, but a cardinal principle is that the lighting should serve the architecture and the symbolism—it must never conflict with them. Eight church interiors are illustrated and examined critically in the article and suggestions are made for improvements in certain respects, particularly by planning so as to provide a coherent flow of light with some modelling from the side, to reveal the shapes of architectural features and to show up faces pleasantly. The article concludes with some notes on maintenance problems.

ELECTRON TRAJECTORIES IN COAXIAL DIODES WITH COMBINED R.F. AND STEADY FIELDS (620).*

By R. Dehn (Research Laboratories).

Wireless Engineer, *Vol.* 33, *pp.* 10-12, *January*, 1956.

The author describes investigations of electron trajectories carried out when using a cylindrical diode in the form of a short coaxial transmission line, mounted in a waveguide system, as a waveform and power monitor for microwaves at frequencies of about 3,000 Mc/s. A much more complex picture than was suggested by the first superficial analysis became apparent. Electrons may return to the cathode either during the first negative half-cycle or after a considerable number of cycles. Likewise they may reach the anode either directly after a few cycles or after a much larger number of cycles, having first suffered two reversals, one near the anode and another one near the cathode. Experimental results suggest that, in general, about half the r.f. power going through the diode, regarded as a coaxial transmission line, is used up in cathode heating by electron bombardment, and that about half the total number of emitted electrons will reach the anode, the remainder being returned to the cathode.

STRUCTURAL TRANSITIONS IN BARIUM TITANATE-ZIRCONATE TRANSDUCER MATERIALS (639).*

By R. C. Kell and N. J. Hellicar (Research Laboratories).

Acustica, *Vol.* 6, *pp.* 235-238, 1956.

The properties of ceramic materials of the barium titanate-zirconate system having compositions with Ti:Zr ratios between 100:0 and 70:30 are described. Curves of permittivity and resonant frequency against temperature give a more sensitive indication of transition temperatures than X-ray powder photographs, as well as being more easily and rapidly obtained.

The most suitable material within this system is that having a Ti:Zr ratio of 95:5. This material has an orthorhombic base which is stable between 5 deg. C. and 50 deg. C. and the change in resonant frequency over this temperature range is only 4 per cent.

CHANGES IN CONDUCTIVITY RESULTING FROM BREAKDOWN IN CADMIUM SULPHIDE SINGLE CRYSTALS (668).*

By J. Woods (Research Laboratories).

Proceedings of the Physical Society, *B*, *Vol.* 69, *pp.* 975-980, 1956.

For small applied fields the resistivity of a pure cadmium sulphide crystal is very high. For fields greater than a critical value, however, dielectric breakdown occurs and large currents flow. If the crystal is protected from destruc-

tion by a limiting resistor it is found on re-measurement at small fields, after the passage of a high current, that the conductivity and photosensitivity have been greatly increased. The increase in conductivity is greater, the larger the current passed through the crystal after the initial breakdown. This activating effect has been examined in detail, and it is shown that the changes which occur as a result of the passage of high currents take place largely in the bulk of the crystal.

THE SUPPRESSION OF SCREEN GRID EMISSION BY CARBON (678).*

By J. A. Champion (Research Laboratories).

British Journal of Applied Physics, Vol. 7, pp. 395-399, November, 1956.

The screen grid emission level which obtains in a receiving valve in which there is no suppression is shown to be of the same magnitude as that of a thin activated layer of barium oxide. It is further shown that the mechanism by which carbon suppresses screen grid emission is by the chemical reduction of deposited barium oxide to barium which evaporates. Below 900 deg. C. this reduction proceeds at a negligible rate and is only sufficient to activate the grid film. At 950 deg. C. the emission decays to a negligibly small value after a few minutes.

ANISOTROPIC GALVANOMAGNETIC EFFECTS IN SEMICONDUCTORS (680).*

By J. R. Drabble and R. Wolfe (Research Laboratories).

Proceedings of the Physical Society, B, Vol. 69, pp. 1101-1108, 1956.

The "many-valley" theory of the galvanomagnetic effects in cubic semiconductors proposed by Abeles and Meiboom is extended to include semiconductors belonging to any crystal class. The theory is applied to the crystal class $\bar{3}$ m. Explicit expressions for the components of the conductivity, Hall conductivity and magnetoconductivity tensors are derived for a six-valley model in which the energy extrema lie on the reflection planes in k-space. These expressions are consistent with preliminary measurements on a single crystal of n-type bismuth telluride in which all the galvanomagnetic effects are anisotropic.

NEW SEMICONDUCTORS WITH THE CHALCOPYRITE STRUCTURE (681).*

By I. G. Austin, C. H. L. Goodman and A. E. Pengelly (Research Laboratories).

Journal of the Electrochemical Society, Vol. 103, No. 11, pp. 609-610, November, 1956.

Compounds of the chalcopyrite group are related to well-known semiconductors such as Ge and the zinc blende compounds. This relationship is discussed briefly and some new data are presented regarding the preparation and properties of five chalcopyrite compounds, $AgInS_2$, $AgInSe_2$, $CuInSe_2$, $AgInTe_2$, and $CuInTe_2$.

THE ZONE REFINING OF IMPURE COPPER (683).*

By E. D. Tolmie and D. A. Robins (Research Laboratories).

Journal of the Institute of Metals, Vol. 85, pp. 171-176, 1956.

The zone-refining process has been applied to copper containing known amounts of various other elements and the segregation of the impurities followed by spectrographic analysis. From the results of preliminary experiments, a rate of zone travel of 11 mm./hr. was selected for a detailed investigation of the segregation produced during the zone-refining of an alloy containing 0·01 wt.-per cent of the elements antimony, chromium, cobalt, iron, manganese, nickel, silicon, silver, and tin. All the added elements segregated in the direction of travel of the molten zone, with the exception of iron, cobalt, and nickel, which segregated in the reverse direction.

The experimental results were used, together with a mathematical expression based upon certain assumptions, to calculate effective partition coefficients for the various impurity elements. A comparison of these values with corresponding values estimated from published phase diagrams showed them to be in approximate agreement, although the amount of segregation was usually less than would have been expected. This showed that the theoretical assumptions upon which the mathematical analysis had been based were not completely fulfilled in these experiments. The assumptions most likely not to be fulfilled are those of homogeneous composition in the liquid phase and equilibrium at the freezing interface.

N-TERMINAL NETWORKS (684).*

By A. Bloch (Research Laboratories).

Wireless Engineer, Vol. 33, pp. 295-300, December, 1956.

Part I of the paper gives some basic theorems (required for Part II) which are generalisations of the corresponding theorems for 2-terminal networks.

Part II of the paper deals with certain applications of these theorems to aerial arrays which have been adjusted for maximum absorption of power from an incident wave. It is shown by reference to the Travelling Wave Theorem for maximum directivity of such arrays, that one half of the energy extracted by such an array from the incident wave is re-radiated in the forward direction with the maximum directivity of which the array is capable.

If an aerial array has been adjusted so as to transfer the maximum amount of power from a wave into a single load, it will have maximum directivity for transmission in the reverse direction if we replace this load by a generator. By designing a feeder network whose action is especially simple to follow it can be seen that, in this case, the voltages supplied to the elements of the array are those required by the Travelling Wave Theorem. Thus the condition for maximum directivity of an aerial array can be proved by network considerations only.

THE EVAPORATION OF IMPURITIES FROM SILICON (689).*

By S. E. Bradshaw and A. I. Mlavsky (Research Laboratories).

Journal of Electronics, Vol. 2, pp. 134-144, September, 1956.

It is shown that the concentration of impurity in a silicon crystal grown in a vacuum is governed by the rate of evaporation and the growth conditions. Three cases of practical interest are distinguished :

(*i*) When evaporation of volatile impurities from the melt is substantially complete before growth of the crystal is begun, boron and aluminium are the only residual impurities from groups 3 and 5.

(*ii*) An added impurity, such as phosphorus, is distributed uniformly in a crystal when the growth time, from the moment of addition, has a critical value.

(*iii*) Repeated addition of an impurity, such as antimony, to a melt containing an impurity of opposite type, produces a series of identical *p-n* junctions in the growing crystal, the type of junction produced being controlled by the growth conditions employed.

Equations describing the combined effects of evaporation and segregation are derived, and the rates of evaporation of certain impurities calculated.

RESISTANCE-CAPACITANCE TUNED AMPLIFIERS USING NEGATIVE FEEDBACK (690).*

By D. J. O'Connor (Research Laboratories).

Electronic Engineering, Vol. 28, pp. 536-539, December, 1956.

The transfer function of an LC tuned amplifier is compared with that obtained for a feedback amplifier using particular types of RC feedback networks. A design procedure is developed which permits the design of circuits having predicted performance.

THE EVAPORATION OF BARIUM FROM "L" CATHODES (697).*

By I. Brodie and R. O. Jenkins (Research Laboratories)

Journal of Electronics, Vol. 2, pp. 33-49, July, 1956.

To meet the demand for a better cathode for microwave beam devices than the conventional alkaline earth oxide type, the various types of barium dispenser cathode have been developed, the first of which was the " L " type originally described by Lemmens and others (1950). By altering the porosity of the tungsten or by varying the actual barium compound used it is possible to make " L " cathodes with differing characteristics, and it was to assess the merits of various modifications that the work described was begun. At the same time, such measurements can be used to investigate some of the mechanisms taking place in the cathode. Two previous groups of workers have reported such measurements (Rittmer *et al.*, 1954, and Schaefer and White, 1952) and their conclusions disagree to some extent.

The results obtained in this work are thus discussed in the light of these previous experiments and also with the relevant thermochemical data. In addition, the evaporation measurements are correlated with emission data to give an assessment of some of the types of cathodes under different operating conditions.

ON SPACE CHARGE WAVES (701).*

By R. H. C. Newton (Research Laboratories).

Journal of Electronics, Vol. 2, pp. 441-450, March, 1957.

In 1939 Hahn (1939) analysed the case of an electron beam in a collimating magnetic field under certain conditions. One of these conditions was that the beam is initially fully neutralised by a background of heavy positive ions. His results have been applied to many problems associated with beam devices, and have shown good agreement with practice, at least under " small signal " conditions. It is therefore of interest to re-examine the problem, and to attempt to carry through the analysis without assuming space charge neutralisation, since most beam devices, such as velocity modulation tubes, operate under reasonably good vacuum conditions, and the beam is almost never in a completely neutralised state.

The purpose of this note is to derive the wave equation in such a manner that the analysis holds good when no positive space charge is present. The calculation is carried as far as possible without making small signal assumptions, and then, in order to compare results with those of earlier writers (Ramo 1939, Warnecke and Guenard 1951), an approximate equation is obtained, by neglecting second order terms in the wave equation, and it is seen that the approximate wave equation is identical with that given by Warnecke and Guenard (1951), who used Hahn's positive ion hypothesis.

Also, a method for determining the boundary conditions when the beam is " sausageing " slightly and no positive ions are present is given for the " small signal " case.

LUMINESCENCE IN ZnS: Cu, Cl SINGLE CRYSTALS (705).*

By T. B. Tomlinson (Research Laboratories).

Journal of Electronics, Vol. 2, pp. 291-300, November, 1956.

The impurity responsible for the green and blue bands in " spectrographically pure " single crystals of zinc sulphide is proved to be copper, in conjunction with chlorine. The crystal growth process tends to exclude chlorine so that introduction of copper results in luminescence typical of a low chlorine content, i.e. there is no green-2 band and the electroluminescence is blue at room temperature. The diffusion rate of chlorine is found to be much less than that of copper so that attempts to introduce both copper and chlorine into the crystals were unsuccessful. The provision of copper during crystal growth permits the retention of a greater chlorine content. This gives both the green-2 band and green electroluminescence.

TRANSISTORS—CIRCUITS AND SERVICING.

By B. R. Bettridge (Valve and Electronics Department).

Published for " Wireless and Electrical Trader " by Trader Publishing Co. Ltd., 23 pp., price 2s. 6d.

This booklet explains in simple practical terms how transistors work, how they are used in radio circuits, and the best methods to employ when servicing equipment that uses them. The treatment is almost entirely descriptive, and is intended primarily for the service engineer. The physical properties of the transistor are explained, and its behaviour compared with that of the thermionic valve. Transistor circuits, including power supply arrangements, are shown in diagrams. Servicing hints are dealt with as occasion arises, and a simple method of testing transistors is described.

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